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Lake Simcoe Water Quality Update

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Lake Simcoe Water Quality Update

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Cover photograph: On Sibbald Point looking east to Duclos point, with the Georgina Island Ferry in the distance. Credit: Lake Simcoe Fisheries Assessment Unit, Ministry of Natural Resources

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Lake Simcoe, Ontario, Canada

Chapter 1
Introduction

chapter one

Ontario is a province with abundant freshwater resources, and Lake Simcoe is one of particular importance, due in part to its size and location. Lake Simcoe is the largest lake in southern Ontario (after the Great Lakes) with a surface area of 722 km^2. Situated only 50 km north of Toronto, Lake Simcoe is easily accessible to millions of people in southern Ontario and neighbouring U.S. states. The lake supports a year-round sport fish industry that provides over 1 million angler hours per year. Altogether, recreational activities generate over $200 million per year. Lake Simcoe has 6 drinking water treatment plants (WTPs) that provide a drinking water source for several communities on the watershed. It also assimilates wastewater from 14 municipal water pollution control plants (WPCPs).

Land use changes in the Lake Simcoe watershed have put pressure on the lake's ecosystem. Land use within the watershed is primarily agricultural (47% of total area), and an increasing amount of land is being developed to support some of the fastest growing urban centres in Canada. Agricultural practices release nutrients and other pollutants from fields into streams that drain into the lake. Urban areas feature hardened surfaces such as roads and roofs that capture pollutants, and runoff from these surfaces is channelled by storm sewers directly into the lake in some areas. Point sources of pollutants, such as WPCP outfalls, discharge straight into the lake or rivers, and atmospheric pollutants are deposited directly to the lake surface.

Holland Marsh looking north towards Bradford. Credit: Nick Wilson

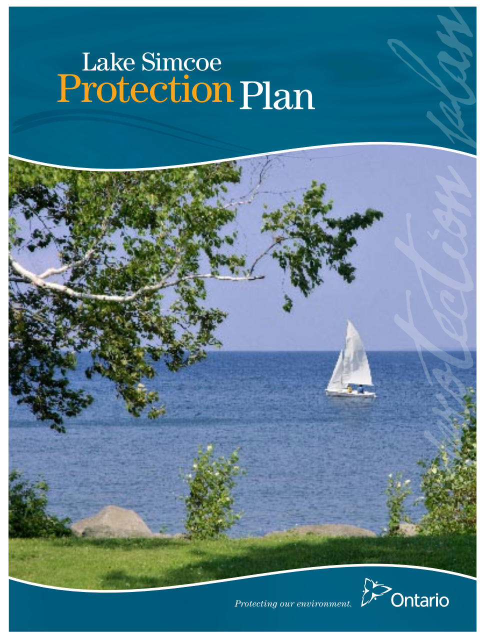
Concerns about water quality issues in Lake Simcoe first materialized in the late 1970s and early 1980s. Lake trout and whitefish populations were in decline and the most likely cause was eutrophication. This prompted the Ministry to initiate water quality monitoring in Lake Simcoe. A full suite of water chemistry samples were first collected in 1971, and the current monitoring program began in 1980. The initial work confirmed that excess nutrients were entering the lake and a phosphorus control strategy was recommended.

The Lake Simcoe Environmental Management Strategy (LSEMS) was comprised of the Lake Simcoe Region Conservation Authority (LSRCA), Ontario ministries, municipalities and other stakeholders, and had an objective of improving and protecting the health of the Lake Simcoe watershed ecosystem. Collaborative efforts on Lake Simcoe under LSEMS grew and lasted for over two decades. In addition to lake monitoring and research, phosphorus load reduction and dissolved oxygen concentration targets were developed, and the implementation of numerous individual environmental projects reduced phosphorus export to the lake.

Despite improvements in lake water quality, sustained efforts to improve the health of the lake ecosystem are required. The Government of Ontario announced plans to create a Lake Simcoe Protection Act and Protection Plan in 2007 as part of its strategy to restore and protect the lake. The Act received Royal Assent in December 2008 and the Lake Simcoe Protection Plan (LSPP) was approved on June 2, 2009 (see http://www.ontario.ca/lakesimcoe).

Eutrophication and Its Effects

- Elevated phosphorus concentrations increase the growth of aquatic plants, including algae
- Decaying algae at the bottom of the lake depletes hypolimnetic oxygen during summer stratification
- The lack of hypolimnetic oxygen limits the survival and reproduction of coldwater fish that cannot tolerate the warmer temperatures above, and young fry experience greater predation at shallower depths



Rocks in the water off Sibbald Point. Credit: LSFAU

Based on expert advice from scientists and consultation with the watershed community, agencies, municipalities, First Nations and stakeholders, the plan sets a new standard for environmental protection in the province and provides a strategy to help restore and protect the health of Lake Simcoe. Water quality forms a key component of the LSPP, and several stressors were identified for the lake, including:

- nutrients (mainly phosphorus)
- pollutants (metals, chloride and organic chemicals)
- pathogens
- climate change
- invasive species

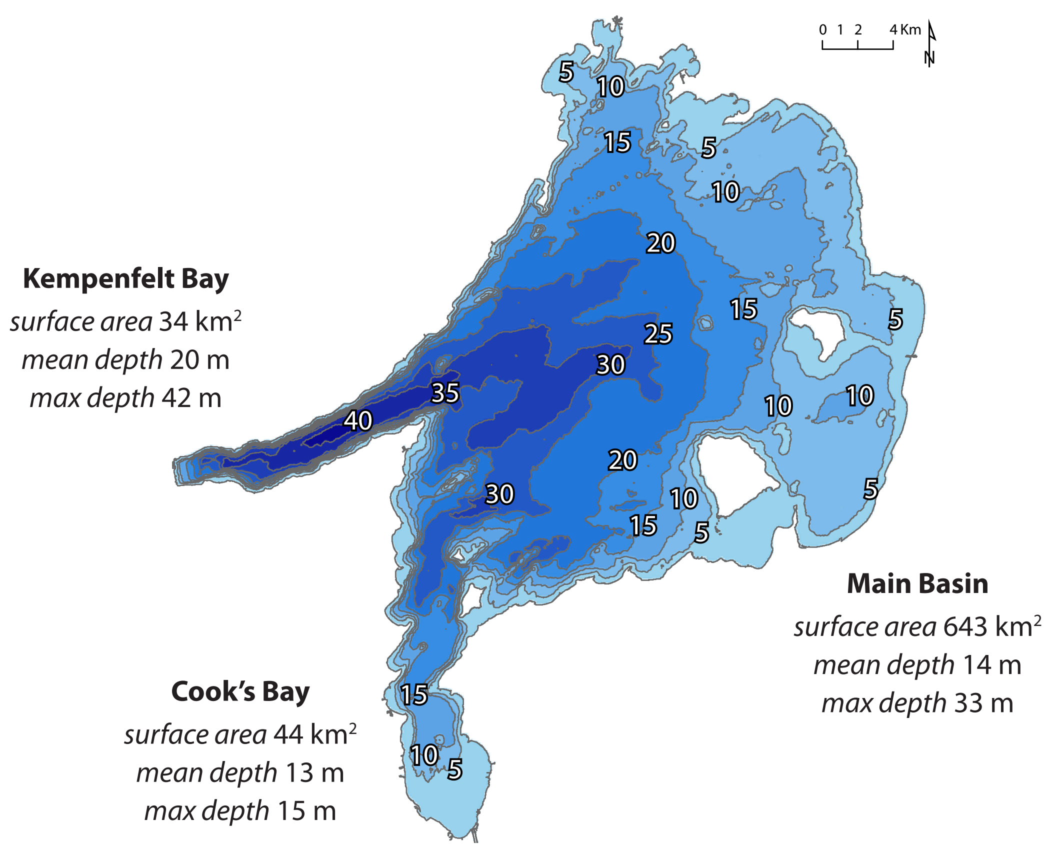
This report will present information on the past 29 years of water quality monitoring in Lake Simcoe with a particular focus on the above stressors. The purpose of this report is to provide an update on recent water quality measurements in the lake as well as to assess the long term trends in water quality with respect to interacting lake processes and effects of stressors. It will also provide a baseline description of Lake Simcoe water quality in advance of LSPP implementation.

Filling tubes for phosphorus analysis at station K42 in Kempenfelt Bay

Chapter 2
Site Description and Methods

chapter two

Mean long term annual precipitation around the lake is approximately 1000 mm, of which about 75% falls as rain. The long term mean annual temperature is 6.7 °C, the January mean is -8.1 °C and the July mean is 20.5 °C. The lake is dimictic (turns over in the spring and fall) and freezes over completely in most winters. Lake Simcoe has two bays, the narrow and deep Kempenfelt Bay and shallow Cook's Bay, and a large main basin that is quite shallow on the east side. Lake Simcoe drains through a single outflow at Atherley Narrows and has a flushing time of approximately 11 years (LSRCA and OMOE 2009). The size of the terrestrial watershed is 2899 km^2. Lake Simcoe is a hard-water lake (mean calcium concentration of 41 mg/L, mean alkalinity of 116 mg/L, mean sulphate concentration of 20 mg/L) due to the limestone bedrock underlying the catchment. Clays and organic soils are the prevalent soil types.



Bathymetry information derived by the OMNR from Canadian Hydrographic Service original depth sounding field sheet, 1957, scale 1:36,000. This map should not be relied on as a precise indicator of routes or locations, nor as a guide to navigation. The OMNR shall not be liable in any way for the use of, or reliance upon, this map or any information on this map.

A fyke net, which is used by the LSFAU for nearshore fish surveys, on the south shore of Kempenfelt Bay, with Big Bay Point in the distance. Credit: LSFAU

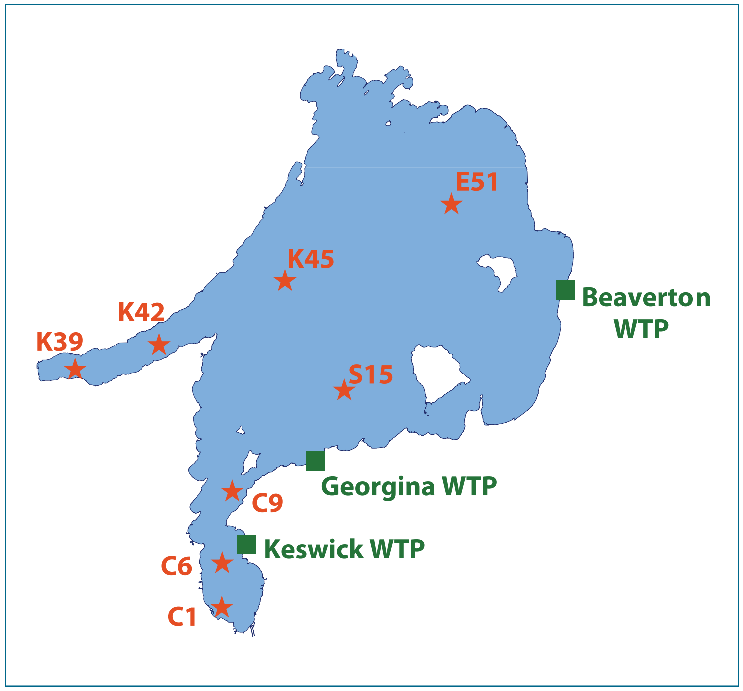
Decades of monitoring and research by the Ontario Ministries of the Environment and Natural Resources (OMOE and OMNR) and the LSRCA have created a strong base of information on Lake Simcoe. Studies have investigated phosphorus and metals in sediments, surveyed algae, macrophytes, benthic invertebrates and fish, and modelling exercises have explored lake chemical processes and hydrodynamics. Several reports summarizing monitoring efforts have also been released, including phosphorus, nitrogen and chloride loading reports, basin wide reports as well as lake water quality reports on previous years of data extending back to 1971 (e.g., Nicholls 1998; Nicholls 2001; Eimers and Winter 2005).

The lake data presented in this report come from 8 stations that have been monitored in collaboration with the LSRCA since 1980 (except for S15, which has been monitored since 1985), although not all parameters were analysed for the entire time period. Samples from the euphotic zone were collected every two to three weeks during the ice-free season (May–October) at each station. Measurements of temperature and dissolved oxygen were also obtained at 1-m intervals through the water column. In addition to the lake stations, samples were collected at the lake outflow (1971–present) and from the intake pipes

Measured Parameters

- nutrients: total phosphorus, phosphate, total nitrogen, total ammonia, nitrate plus nitrite
- algae: chlorophyll *a*, biovolume
- pH, alkalinity, conductivity
- dissolved organic and inorganic carbon, silica
- other ions: calcium, manganese, sodium, potassium, chloride, sulphate
- water clarity (Secchi disk depth)
- temperature and dissolved oxygen profiles

of three WTPs (Beaverton, Georgina, previously known as Sutton, and Keswick) (1984–present). Outflow and WTP samples were collected year round every two weeks or more frequently, and were analysed for nutrients, chlorophyll *a* and chloride only. All parameters were tested to see whether there were significant increasing or decreasing trends over time using the non-parametric Mann-Kendall test with the Sen's slope estimator. Mean 2004–2008 values are also presented with ± 1 standard deviation shown in brackets. Annual ice-free averages (± stdev) for all parameters presented are available in the Appendix, which can be accessed interactively when in PDF format.



Lake Simcoe sampling stations that are summarized in this report

Swans near Sand Islands, at the southwest corner of Georgina Island. Credit LSFAU

Chapter 3
Results and Discussion

chapter three

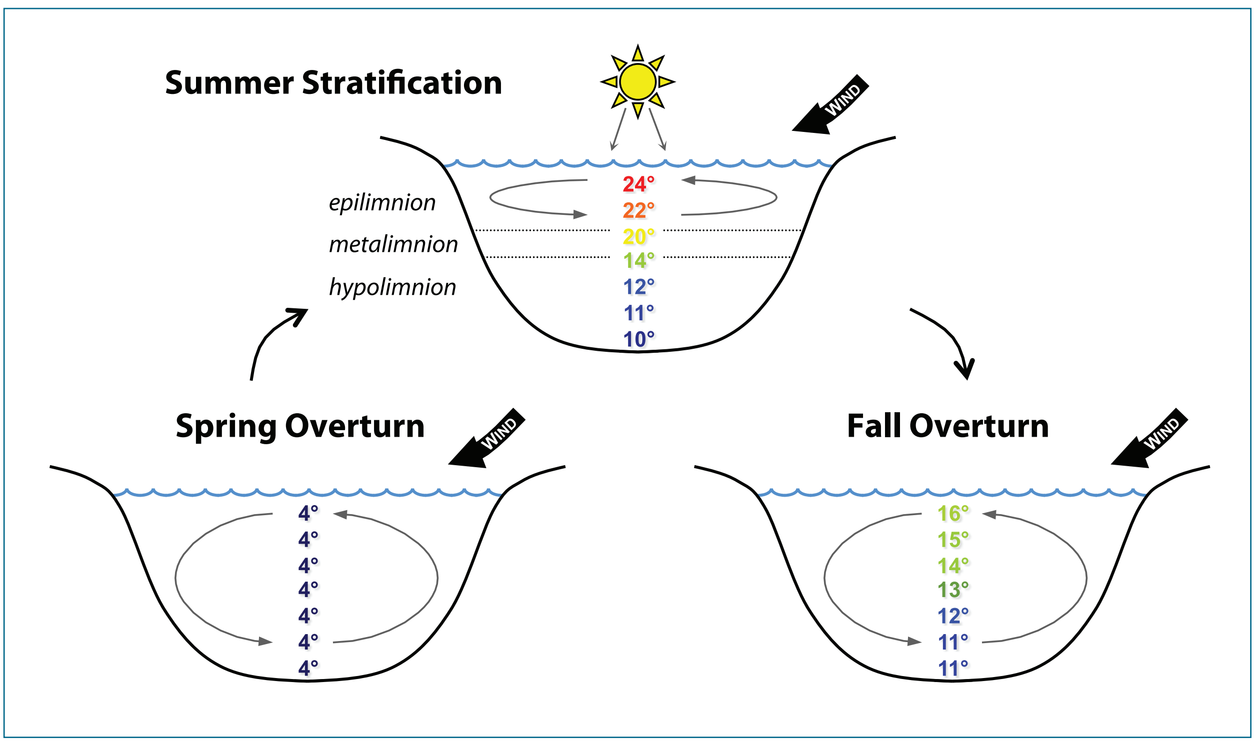
Physical Processes and Climate Effects

Wind and solar energy drive physical processes in lakes. Lake currents are generated by wind that blows across the lake surface, creating strong circulation patterns and mixing the lake water along vertical and horizontal gradients. Since Lake Simcoe has a relatively large surface area to depth ratio, it has good exposure to wind and is very well-mixed. Evidence of this mixing is shown by similar concentrations of certain ions (such as chloride) across the lake. Vertical lake mixing is also affected by warming and cooling. Water density is temperature dependent, and as the density gradient increases, greater amounts of energy are required to mix the water column, eventually causing the water column to stratify into separate horizontal layers.

The shallow areas of Lake Simcoe such as station C1, which is 3 m deep, remain mixed throughout the entire year. Weak stratification lasting a few weeks at a time occurs in slightly deeper areas. The deepest areas of the lake (> 15 m)

What causes stratification?

- The lake is mixed in the spring and fall under isothermal (equal temperature) conditions.
- As the lake surface warms in the spring and early summer, it becomes less dense than the underlying water and stratifies, forming a warm upper layer and cold bottom layer.
- As the surface cools down in the fall, stratification breaks down and the lake becomes mixed again.
- The lake stratifies again in the winter as the water cools down; water at 4 °C is most dense and sinks to the bottom, while 0 °C ice is less dense and floats.



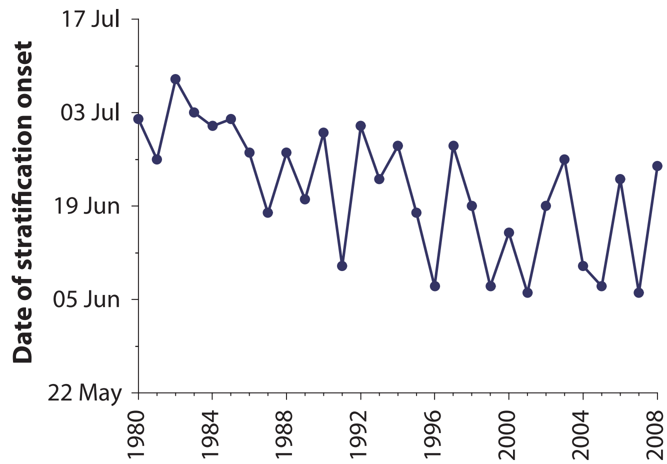
Seasonal stratification and overturn typically seen in Lake Simcoe

typically stratify every year for several months, although the strong currents in Lake Simcoe shift the thermocline and sometimes even disrupt stratification.

Calculations of water column stability at the deep water station (K42) were used to determine the beginning and end of the stratification period, and both have changed significantly over the past three decades (Stainsby et al. submitted). The onset of stratification in the spring is currently 20 days earlier than it was in 1980 and fall overturn is delayed by 15 days. Longer stratification periods may result from shorter periods of ice cover on the lake or more rapid warming in the spring; earlier stratification and greater lake stability are linked to the warmer air temperatures associated with climate change (Hondzo and Stefan 1993). Changes to stratification timing and duration may affect biological and physical aspects of the lake, including phytoplankton communities and hypolimnetic dissolved oxygen levels.

Strength of summer stratification at all lake stations

	Strength
C1	Absent
C6	Weak
C9	Moderate
K39	Moderate
K42	Strong
K45	Strong
E51	Weak
S15	Strong



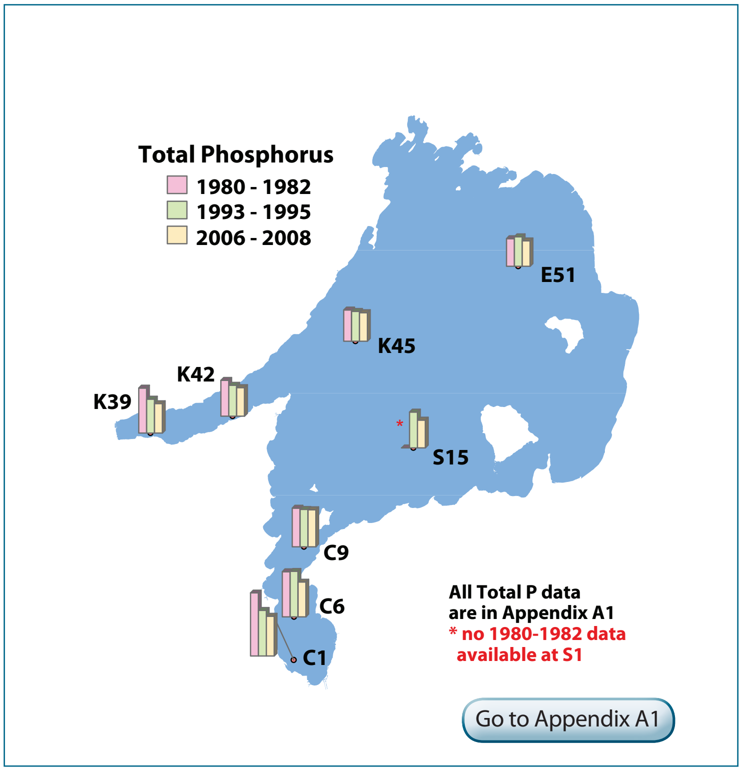
Date of stratification onset at the deepest lake station (K42)

Ice opening up on Lake Simcoe. Credit: LSFAU

Phosphorus and Other Nutrients

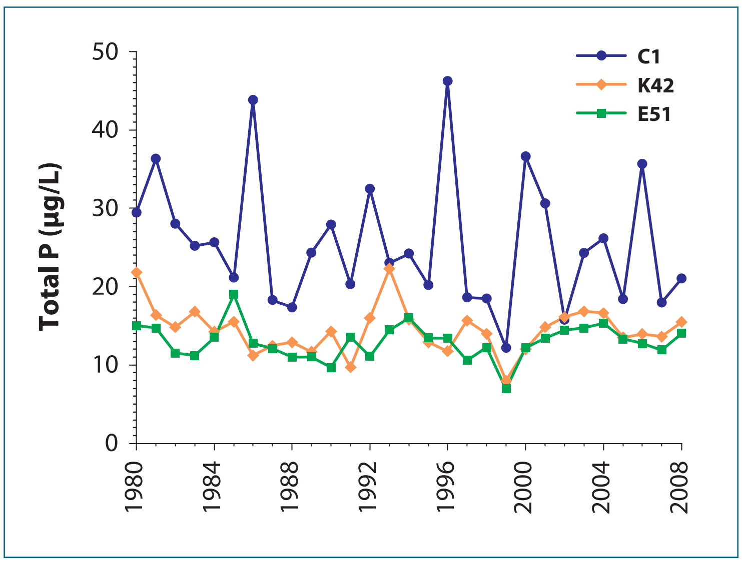
Phosphorus

Phosphorus (P) is the most common limiting nutrient in freshwater lakes and is the limiting nutrient in Lake Simcoe. Elevated P concentrations cause excessive algae and plant growth, which degrade water quality. P inputs to the lake are balanced by processes that remove P, such as plant uptake, sedimentation processes and export through the lake outflow. Over the 29 year period, no significant monotonic trends in total P concentrations (including particulate, organic and dissolved forms) were found. The previous lake report, which examined trends from 1980–2003, found significantly decreasing total P concentrations at stations C1, C9 and K39. However, these declines occurred primarily in the 1980s, while total P concentrations in recent years have remained relatively constant or have increased. Comparing total P concentrations across the lake, the highest concentrations were found in Cook's Bay where the 2004–2008 means ranged from 15 to 23 µg/L, while the lowest total P concentrations were found in the main basin



Total P trends over 29 years and recent averages (± stdev)

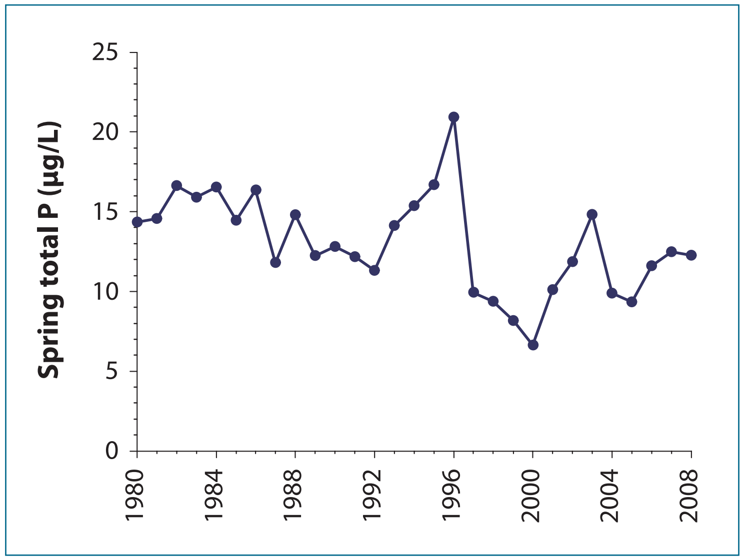
	1980–2008 Trend	2004–2008 Average (µg/L)
C1	-	23.4 (19.6)
C6	-	18.2 (7.0)
C9	-	14.8 (4.0)
K39	-	15.4 (4.2)
K42	-	14.7 (3.7)
K45	-	13.8 (5.8)
E51	-	13.5 (4.3)
S15	-	14.1 (4.9)



Total phosphorus concentrations at three lake stations

with a mean of approximately 14 µg/L. Spring total P concentrations (volume-weighted across the whole lake) have significantly decreased over the past three decades, although, similar to ice-free concentrations, slight increases have occurred in recent years.

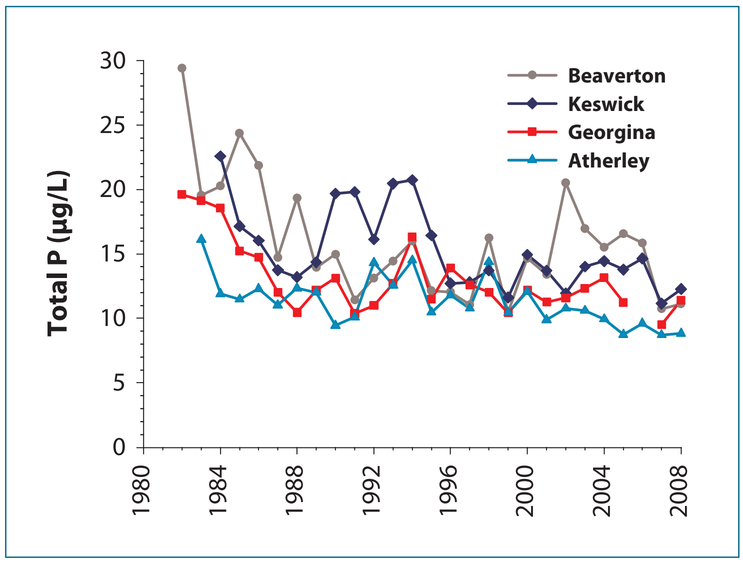
Annual means calculated from year-round data at all three WTP intake pipes and the lake outflow exhibited significant declines in total P concentration from the early 1980s to present. Similar to the lake stations, total P concentration declined substantially through the 1980s and early 1990s and has since remained fairly constant. May–October concentrations at the intakes and outflow also had significant decreasing trends. One explanation as to why significant declines were observed at the intake



Spring total phosphorus concentration volume-weighted across all lake stations

Total P trends over 27 years and recent averages (± stdev) at WTP intake pipes and Atherley outflow

	1982–2008 Trend	2004–2008 Average (µg/L)
Beaverton	↓	13.9 (11.9)
Keswick	↓	13.1 (7.1)
Georgina	↓	12.8 (9.1)
Atherley	↓	9.2 (3.2)

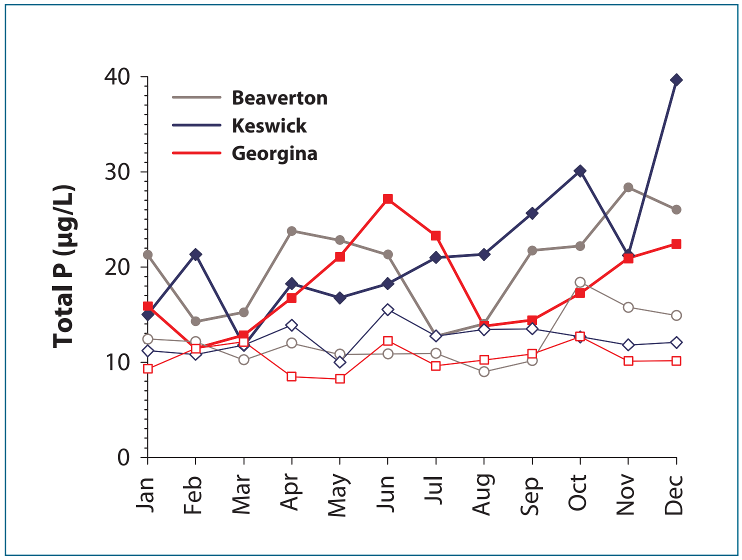


Total phosphorus annual concentrations at WTP intake pipes and Atherley outflow

North Schomberg River. Credit: Jim Eddie

pipes and not at the lake stations is that sampling locations closer to shore are more likely to show changes in loads from the watershed. The lowest total P concentrations across the lake were found at the lake outflow. Nutrient cycling through the lake ecosystem and sedimentation processes remove P from the water column before water reaches the outflow.

At the intake pipes, seasonal trends were observed in the 1980s when total P concentrations were higher, despite concentrations being highly variable over space and time. Concentrations were elevated in the spring months due to high P runoff inputs from the catchment and were typically lower during the summer due to P uptake and sedimentation processes. In the fall, release of P from the sediments during fall mixing as well as increased catchment inputs from fall rains likely caused P concentrations to increase. In recent years seasonal trends are much less apparent, likely due to lower P loads in runoff as well as reduced P release from sediments due to higher oxygen concentrations at the lake bottom. As outlined in the LSPP, the Province is currently working with watershed partners to develop a comprehensive strategy to reduce future phosphorus inputs to the lake from point and non-point sources, including WPCPs, urban stormwater and agricultural runoff, atmospheric deposition and septic systems.



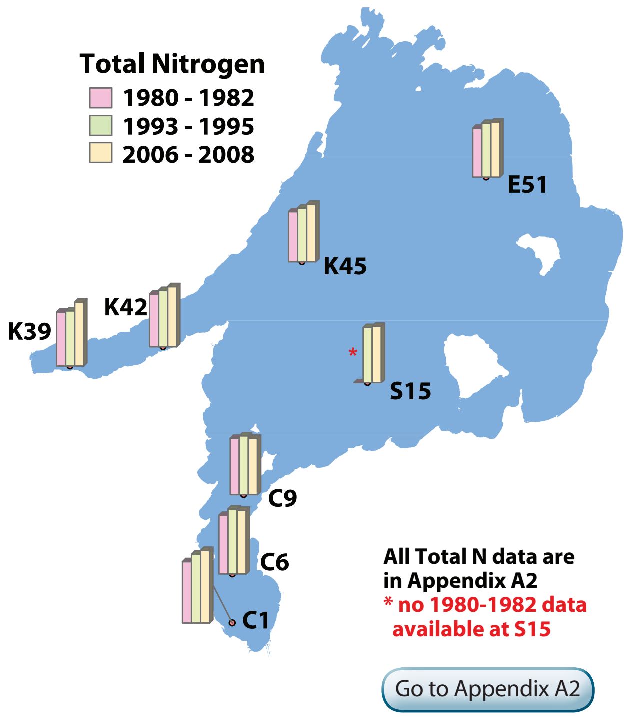
Mean monthly total phosphorus concentrations at WTP intake pipes from 1982–1984 (filled symbols) and 2006–2008 (open symbols)

Confluence of East and West Holland River flowing north into Cook's Bay. Credit: Nick Wilson

Nitrogen

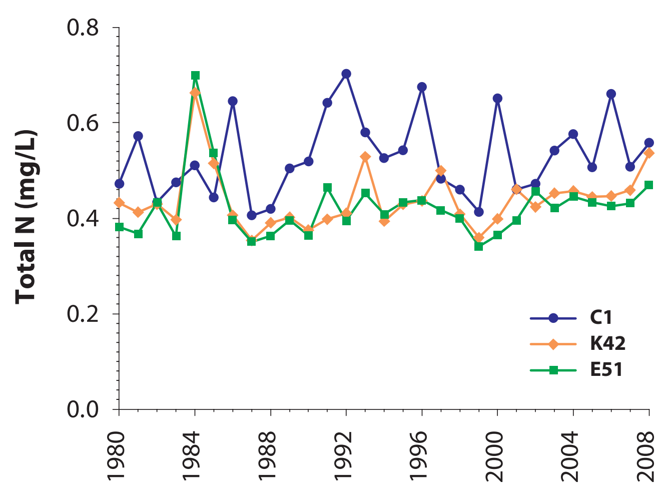
Nitrogen (N) is another important nutrient that can control productivity in freshwater ecosystems under certain conditions (i.e., when P is not limiting). Total N, which includes inorganic, organic and particulate N, did not exhibit any significant trends over time at any station. Current total N concentrations are equivalent to or slightly higher than three decades ago. N is not being targeted specifically under the Protection Plan, although many measures taken to reduce P loadings to the lake will also reduce N loadings.

Credit: Nick Wilson



Total N trends over 29 years and recent averages (± stdev)

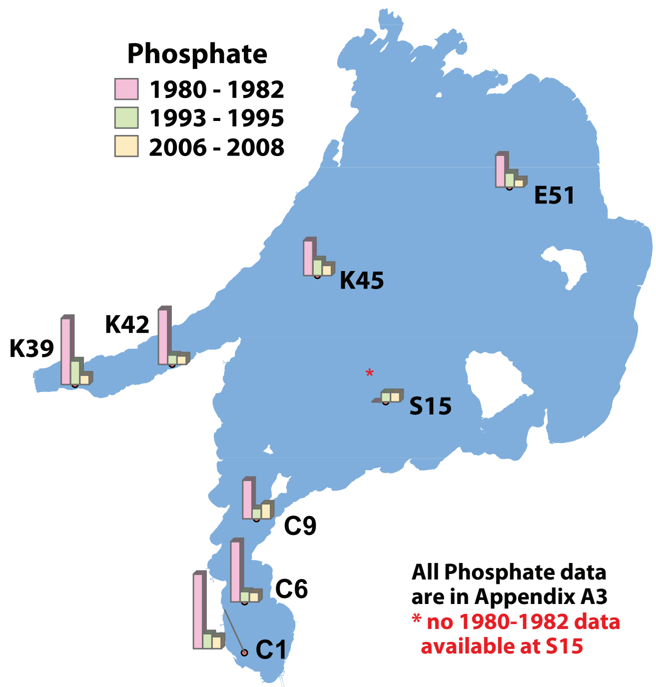
	1980–2008 Trend	2004–2008 Average (mg/L)
C1	-	0.56 (0.18)
C6	-	0.51 (0.11)
C9	-	0.45 (0.05)
K39	-	0.49 (0.09)
K42	-	0.47 (0.09)
K45	-	0.45 (0.05)
E51	-	0.44 (0.05)
S15	-	0.47 (0.13)



Total nitrogen concentrations at three lake stations

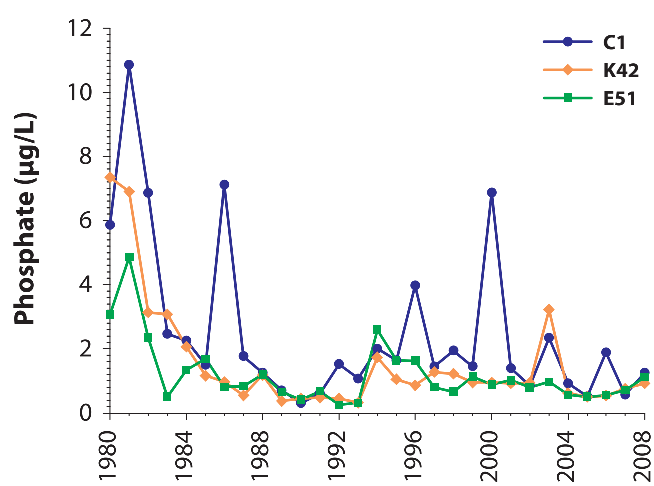
Reactive Nutrients

Phosphate, total ammonia and nitrate plus nitrite are the soluble, reactive and more biologically available forms of the nutrients P and N. Concentrations of phosphate were greatest in the early 1980s, particularly in Cook's and Kempenfelt bays where concentrations have since decreased by 6–7 fold. Phosphate concentration declines were significant over the 29 year period at all stations except S15, which was only monitored since 1985 after major phosphate decreases had already occurred at other stations. Decreases in phosphate can be attributed in part to regulation under the Canadian Environmental Protection Act instituted in 1989, which set limits on phosphate concentrations in laundry detergents (2.2% P by weight). New regulations being proposed would limit phosphate in all detergents (e.g., dishwasher detergent) to 0.5% P by weight by 2010. Another factor contributing to reduced nutrient (total and reactive) concentrations in the lake during the study period is the 1984 diversion of sewage from Newmarket away from Lake Simcoe. Additionally, wastewater treatment has improved over the past few decades. Since 1989, WPCPs that discharge to Lake Simcoe were required to operate under P loading limits resulting in upgraded treatment technology for expanding WPCPs.



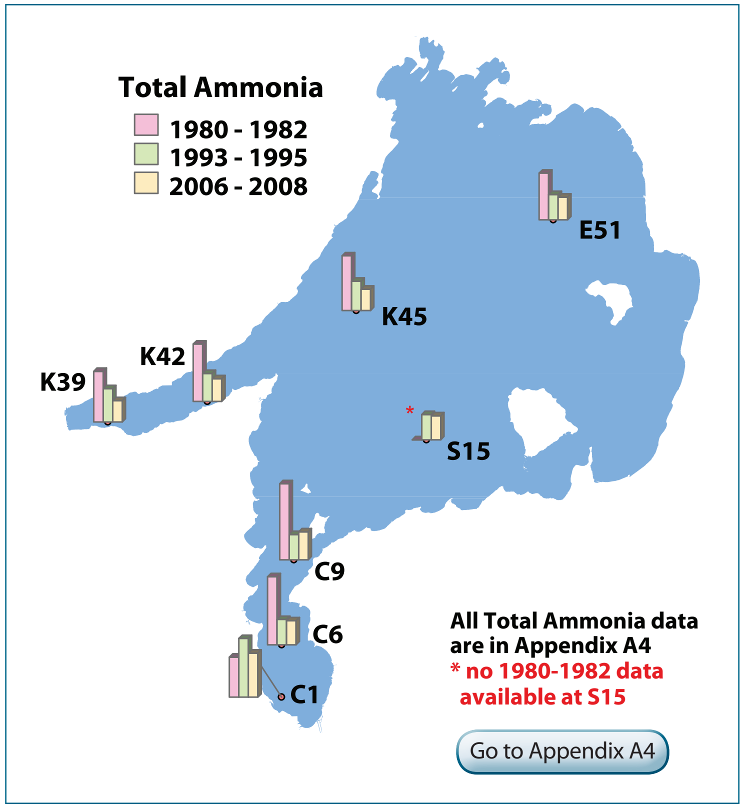
Phosphate 29 year trends and recent averages (± stdev)

	1980–2008 Trend	2004–2008 Average (µg/L)
C1	↓	1.0 (1.2)
C6	↓	1.0 (1.8)
C9	↓	1.3 (4.2)
K39	↓	0.8 (0.6)
K42	↓	0.7 (0.5)
K45	↓	0.8 (0.7)
E51	↓	0.7 (0.7)
S15	-	0.8 (0.8)



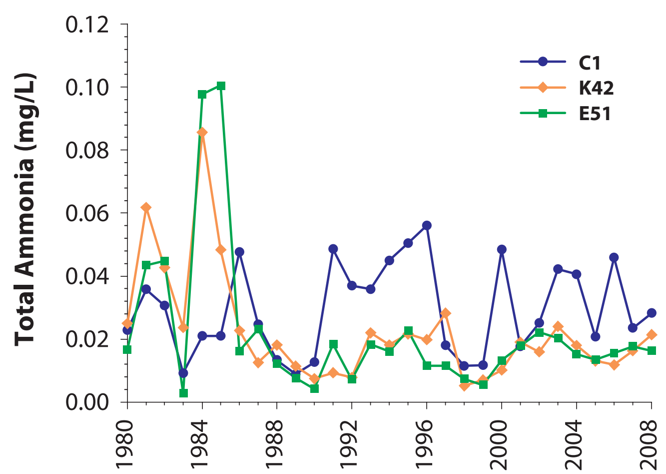
Phosphate concentrations at three lake stations

Total ammonia concentrations are lower now than they were in 1980 at all stations except C1, although the decreases were only significant at three lake stations (C6, K42 and K45). Ammonium (NH_4) is the prevalent form of ammonia in the lake. Within the range of pH and temperatures in the lake, only a small percentage of total ammonia is in the toxic free-NH_3 form. However, occasional peaks in total ammonia occur, and equilibrium calculations suggest that free-NH_3 concentrations exceeded Provincial Water Quality Objectives (PWQO) guidelines of 0.02 mg/L on rare occasions at station C6. Sources of ammonia include reducing conditions that release soluble NH_4 from organic N as well as sewage treatment plant effluent and agricultural runoff.



Total Ammonia 29 year trends and recent averages (± stdev)

	1980–2008 Trend	2004–2008 Average (mg/L)
C1	-	0.031 (0.023)
C6	↓	0.018 (0.012)
C9	-	0.018 (0.016)
K39	-	0.017 (0.011)
K42	↓	0.016 (0.010)
K45	↓	0.014 (0.009)
E51	-	0.016 (0.010)
S15	-	0.016 (0.013)

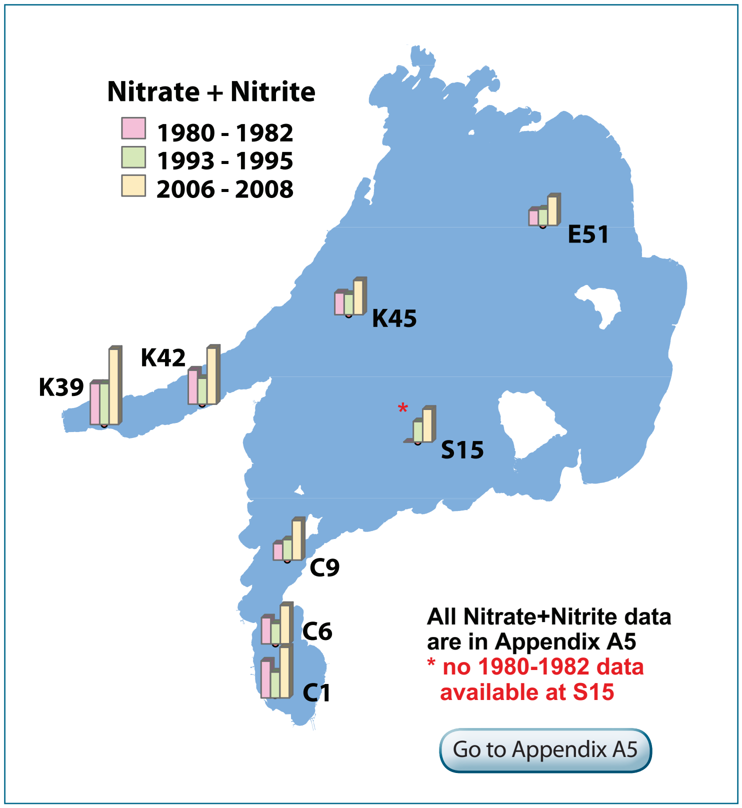


Total Ammonia concentrations at three lake stations

Looking west at Duclos Point. Credit: Nick Wilson

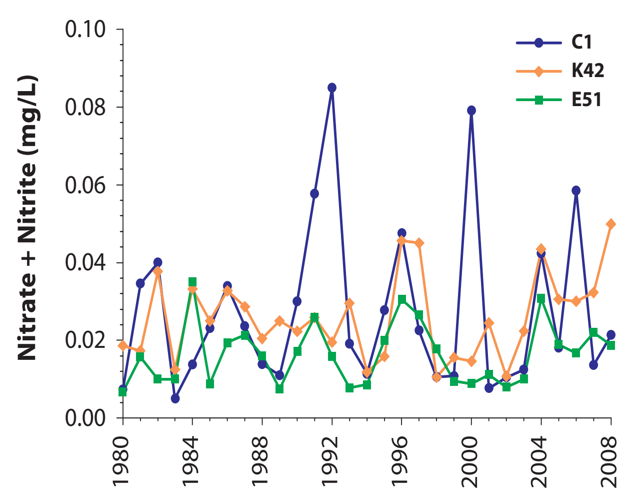
Mean nitrate plus nitrite concentrations appear to have increased slightly in recent years although large interannual variability exists and no significant trends were found at any of the lake stations. Mean nitrate plus nitrite concentrations are highest at K39 and occasionally C1, stations at the far ends of bays closest to tributary outlets and WPCP outfalls.

Innisfil (Alcona) WPCP. Credit: Nick Wilson



Nitrate + nitrite 29 year trends and recent averages (± stdev)

	1980–2008 Trend	2004–2008 Average (mg/L)
C1	-	0.030 (0.058)
C6	-	0.032 (0.039)
C9	-	0.032 (0.030)
K39	-	0.052 (0.037)
K42	-	0.038 (0.032)
K45	-	0.025 (0.024)
E51	-	0.022 (0.020)
S15	-	0.026 (0.023)

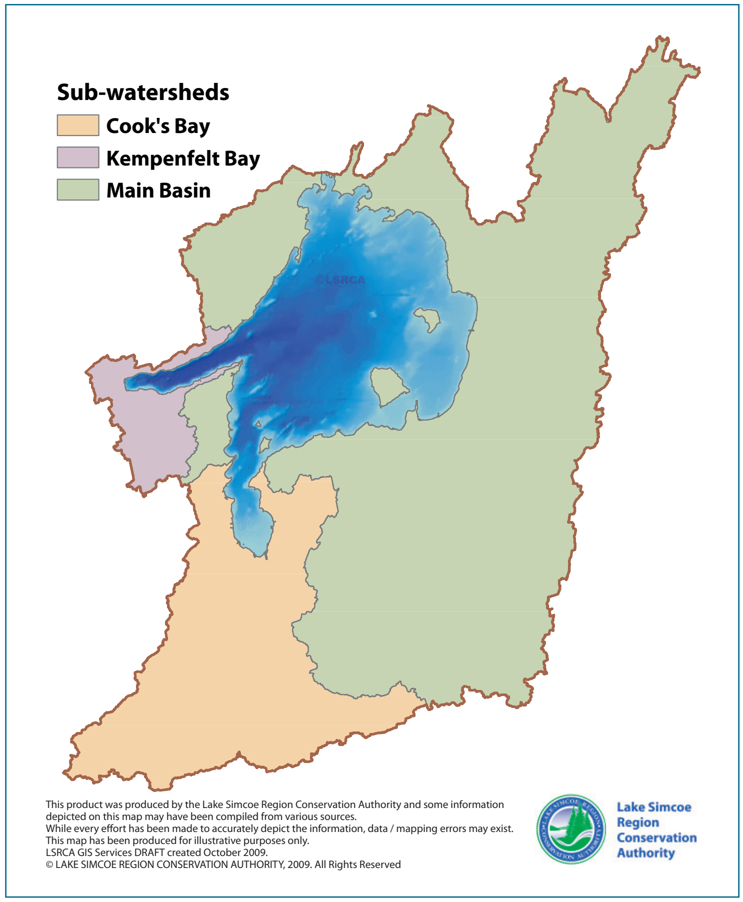


Nitrate + nitrite concentrations at three lake stations

Phosphorus Loads

P loads to Lake Simcoe come from point sources in the watershed such as WPCPs, as well as from non-point sources including urban areas, agricultural areas and rural septic systems. P is also deposited from the atmosphere. Natural background (pre-1800) P loads to the lake were estimated to be approximately 32 tonnes/year (Johnson and Nicholls 1989; Nicholls 1997), while mean loads from 2002–2007 were 72 tonnes/year (LSRCA and OMOE 2009).

Of the 72 tonnes, 20 tonnes enter into Cook's Bay, primarily at the south end, 10 tonnes enter into Kempenfelt Bay and the remaining 42 tonnes are input to the main basin. However, since the main basin is very large, its load per unit volume is only 4 mg/m^3/yr, while shallow Cook's Bay has a volume-weighted load of 61 mg/m^3/yr. Although the lake is well mixed, the effect of these loads to each basin are evident in the spatial variation in total P concentrations, which are highest in Cook's Bay and decrease heading north from nearshore to offshore.



Mean (± stdev) 2002–2007 phosphorus (P) loads, load per unit basin volume and lake water concentrations for Cook's Bay, Kempenfelt Bay and the main basin

	Cook's Bay	Kempenfelt Bay	Main Basin
P load (tonnes/yr)	20 (3)	10 (1)	42 (2)
Volume-weighted P load (mg/m^3/yr)	61 (8)	13 (1)	4 (0.2)
Volume-weighted lake total P (µg/L)	16 (1)	15 (2)	14 (1)

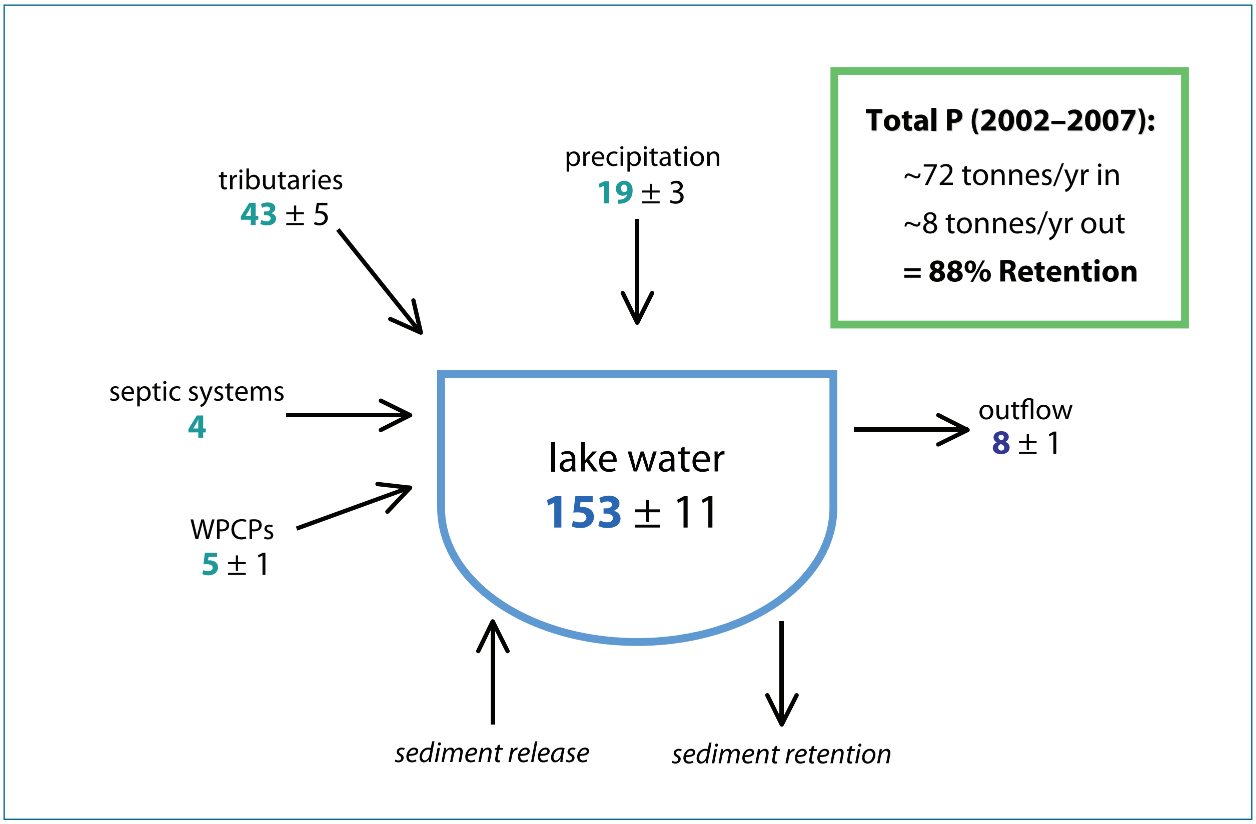
Schomberg River near Schomberg

Precipitation collectors at Ramara sampling site

While approximately 72 tonnes of P are input into Lake Simcoe per year, only approximately 8 tonnes/year leave through the outflow. Internal processes of uptake and sedimentation retain approximately 88% of P inputs within the lake. Although lake sediments are a major sink for P, under certain conditions, P is also released from the sediments as a result of resuspension or chemical processes. One common cause of P release occurs when the sediment-water interface becomes anoxic; however, in recent years dissolved oxygen levels in the deep water of the lake have not gone below 2 mg/L. Organic matter mineralization, high sediment pH, and sulphate reduction are the three other processes by which P is released from lake sediments (Hupfer and Lewandowski 2008). All of these processes are possible in Lake Simcoe, being a relatively productive, hardwater lake with high pH and elevated concentrations of calcium and sulphate. Further research into P release from sediments is needed to better understand the P cycling processes in the lake.

Phosphorus Release from Sediments: Multiple Causes

- P rich sediments may be resuspended into the water column from processes such as wind action in shallow areas (e.g., Cook's Bay)
- Oxygen depletion due to organic matter decomposition by microbes at the lake bottom creates reducing conditions, which makes iron soluble and releases P (Mortimer 1942)
- Organic matter decomposition releases P (Prairie et al. 2001)
- Phosphate binding to iron can be reduced due to competition with hydroxide ligands under high pH (Andersen 1975)
- Sulphate reduction in the lake sediments produces sulphide, which binds iron, preventing iron binding to phosphate (Caraco et al. 1989)

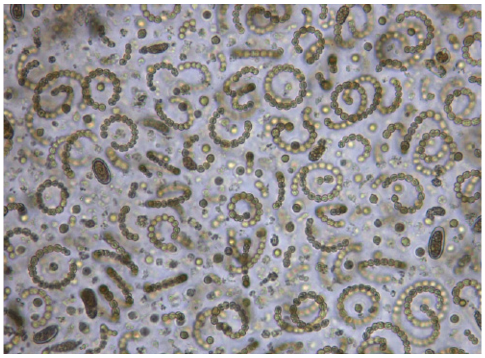


Total P mass balance for Lake Simcoe averaged from 2002–2007

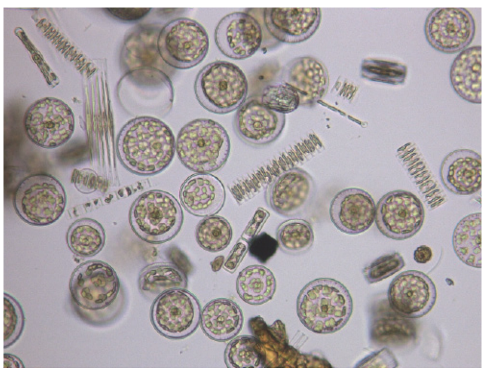
Algae, water clarity and macrophytes

Chlorophyll

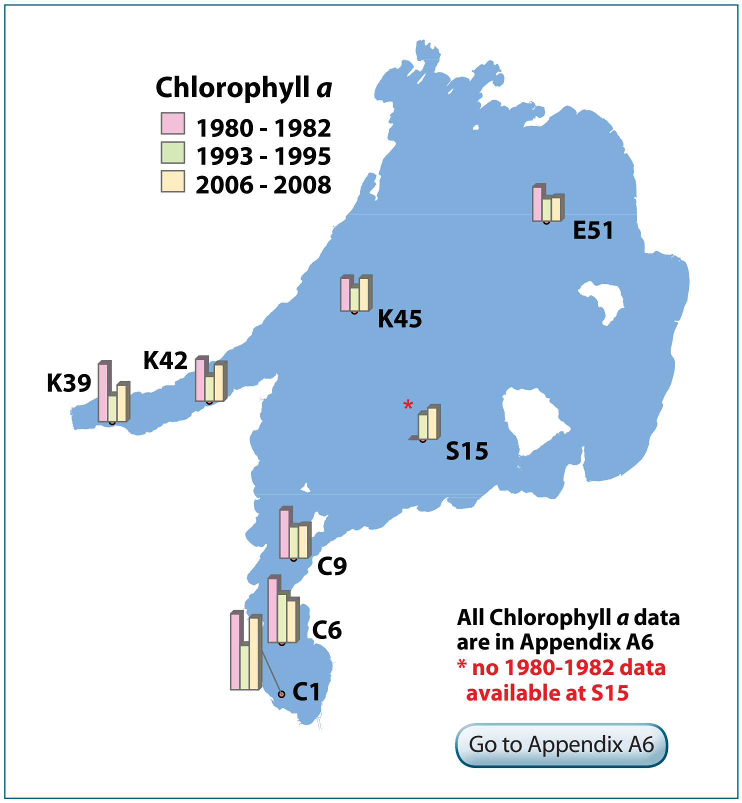
Chlorophyll *a* concentrations are used as a measure of phytoplankton abundance. Concentrations of chlorophyll a generally decreased through the 1980s and early 1990s. Since then, chlorophyll a concentrations have levelled off at the shallower lake stations (all 3 Cook's Bay stations and E51 in the main basin) and have increased slightly at the deeper lake stations (both Kempenfelt Bay stations, and K45 and S15 in the main basin). Overall, decreases in chlorophyll a concentrations over the past three decades were only significant at the shallower stations.



Cyanobacteria from the Holland River

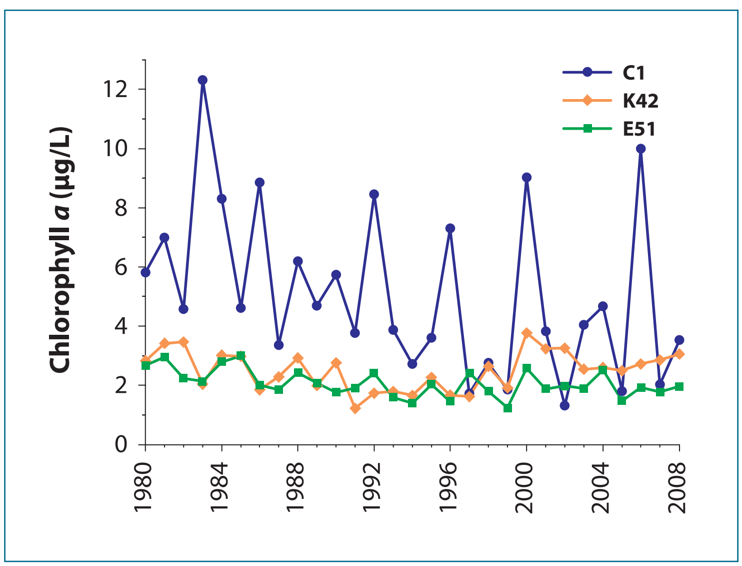


Diatoms collected from the Georgina WTP intake pipe



Chlorophyll *a* 29 year trends and recent averages (± stdev)

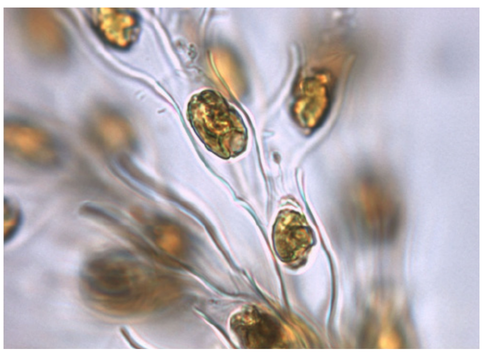
	1980–2008 Trend	2004–2008 Average (µg/L)
C1	↓	4.2 (8.1)
C6	↓	2.9 (1.7)
C9	↓	2.5 (1.6)
K39	-	2.7 (1.8)
K42	-	2.8 (1.6)
K45	-	2.5 (1.5)
E51	↓	1.9 (1.2)
S15	-	2.4 (1.6)



Chlorophyll *a* concentrations at three lake stations

Phytoplankton Biovolume

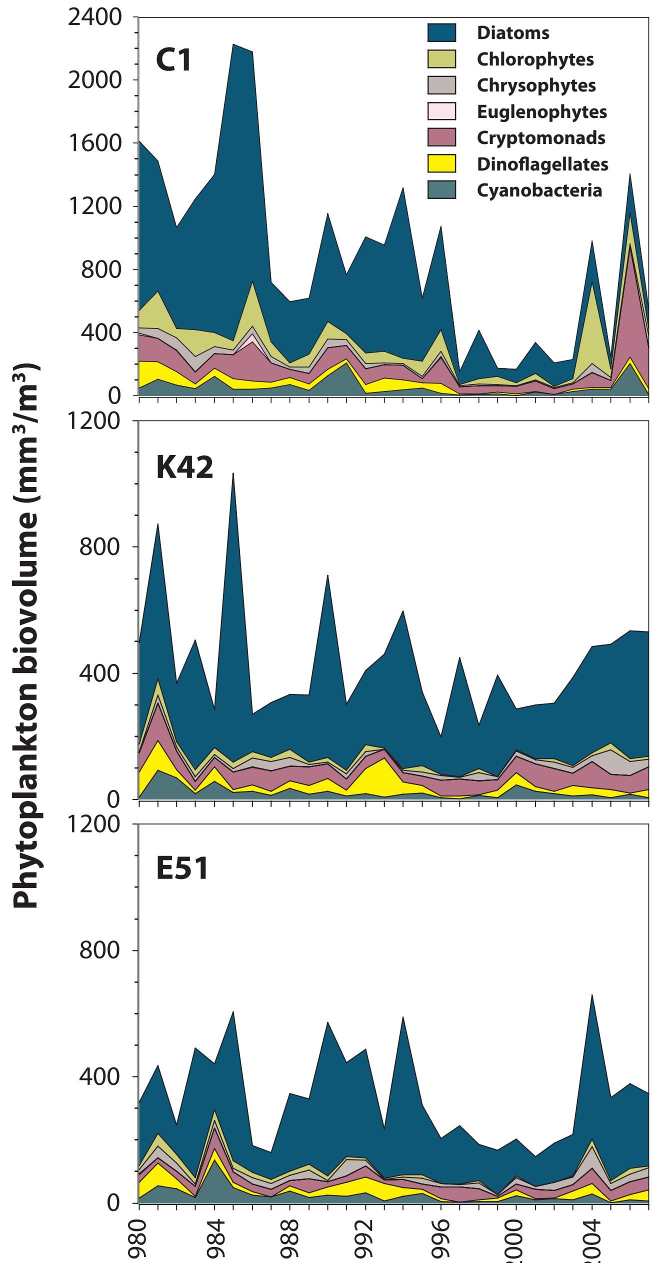
Biovolume is another measure of phytoplankton abundance based on counts of individual algae and mean cell volumes. Similar to chlorophyll *a* trends, total biovolume declined through the 1980s and were at the lowest levels during the late 1990s but have since increased (Winter et al submitted). Decreases in total biovolume were significant at all three stations in Cook's Bay. The greatest biovolumes were found in Cook's Bay, where they were two to three times greater than those in the main basin. The most abundant group of algae found in Lake Simcoe are diatoms (Bacillariophyceae), which comprise two-thirds of the total algal biovolume of the lake. Cryptomonads (Cryptophyceae) and dinoflagellates (Dinophyceae) are next most common of the remaining groups. The blue-green algae (Cyanobacteria) and green algae (Chlorophyceae) are less common and their abundance has decreased significantly at almost all lake stations. These algal groups in particular are more abundant under higher nutrient conditions. Algal populations are



Colonial chrysophyte, *Dinobryon*

Total, cyanobacteria and chlorophyte biovolume 28 year trends

	1980–2007 Biovolume Trend		
	Total	Cyano	Chloro
C1	↓	↓	-
C6	↓	↓	↓
C9	↓	↓	↓
K39	-	↓	↓
K42	-	↓	↓
K45	-	↓	↓
E51	-	↓	↓
S15	-	-	↓



Phytoplankton biovolume figures for all stations are in Appendix A7

Go to Appendix A7

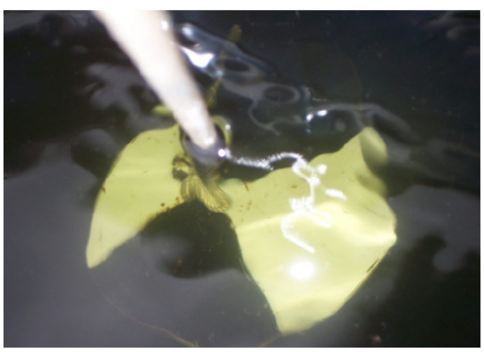
Biovolume of algal groups at three lake stations. Note: the C1 y-axis scale is twice as large.

controlled by P and silica concentrations, light, temperature, water turbulence and zooplankton grazing. The changing combination of conditions causes frequent shifts in abundances of each group, and the shift in community composition at station C1 is being investigated.

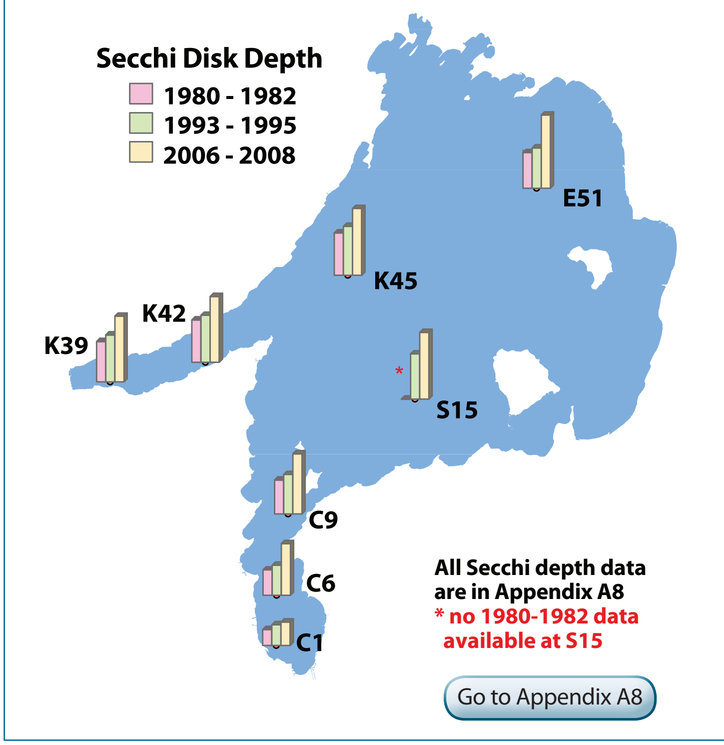
Water Clarity

Water clarity, which is measured as Secchi disk depth, is affected by algae, suspended sediment and coloured organic matter. Over the past three decades, water clarity has increased at all lake stations. Since 1980, water clarity across the lake has improved by 30 to 50%. The most substantial increases in water clarity began in the 1990s, a period of time coinciding with P load reductions and the establishment of zebra mussels. Because zebra mussels are highly effective filter feeders, their colonization of a lake can produce dramatic increases in water transparency (Holland 1993).

Because Lake Simcoe is a hardwater, high calcium marl lake, natural events called whitings occur on occasion, where calcium precipitates out of solution as calcium carbonate, a white solid. The precipitation occurs due to higher temperatures and photosynthesis levels that shift the balance between carbon dioxide, bicarbonate and carbonate. During whiting events,

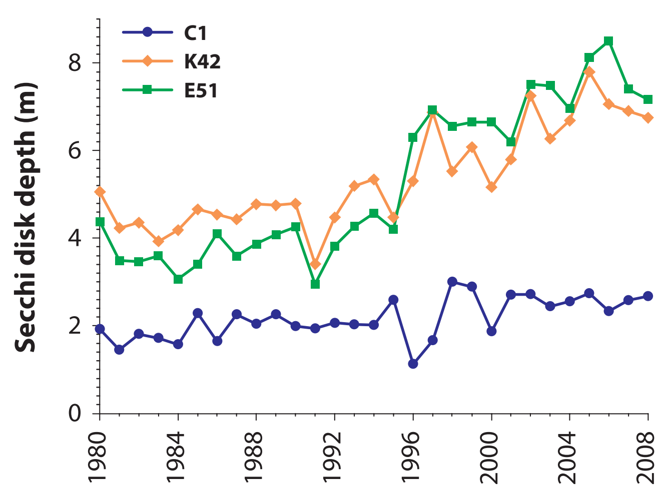


Secchi disk



Secchi disk depth 29 year trends and recent averages (± stdev)

	1980–2008 Trend	2004–2008 Average (m)
C1	↑	2.6 (0.6)
C6	↑	5.4 (1.3)
C9	↑	6.4 (1.4)
K39	↑	7.2 (2.1)
K42	↑	7.0 (2.0)
K45	↑	7.1 (1.8)
E51	↑	7.6 (2.2)
S15	↑	7.1 (1.9)



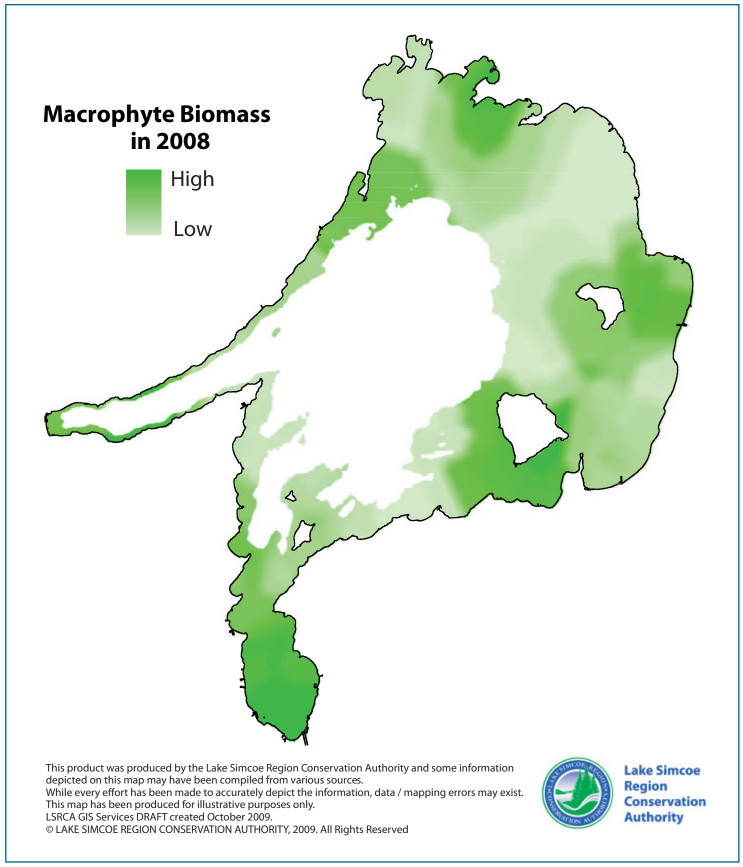
Secchi disk depth concentrations at three lake stations. Note: maximum water depth at station C1 is 3 m.

water clarity is reduced. The calcium carbonate precipitate gradually settles out of the water column forming a white layer (called a varve) on the sediment surface. Researchers have postulated that zebra mussels, which have high calcium requirements for their shells, have reduced the frequency of whiting events in the Great Lakes, increasing water transparency (Barbiero et al. 2006). Increased water clarity due to fewer whiting events could increase phytoplankton or macrophyte abundance due to light penetration to greater depths. Reduced whiting events may affect phosphate concentrations, as co-precipitation with calcium removes reactive P from the water column.

Macrophytes

Increased water clarity and elevated nutrient concentrations create favourable growth conditions for macrophytes. Excessive macrophyte growth clogs open-water, making swimming and boating less enjoyable. The decomposition of dead plants also consumes oxygen, but macrophytes typically only grow at shallow depths where the water is well-mixed and oxygenated, thus oxygen depletion is of less concern.

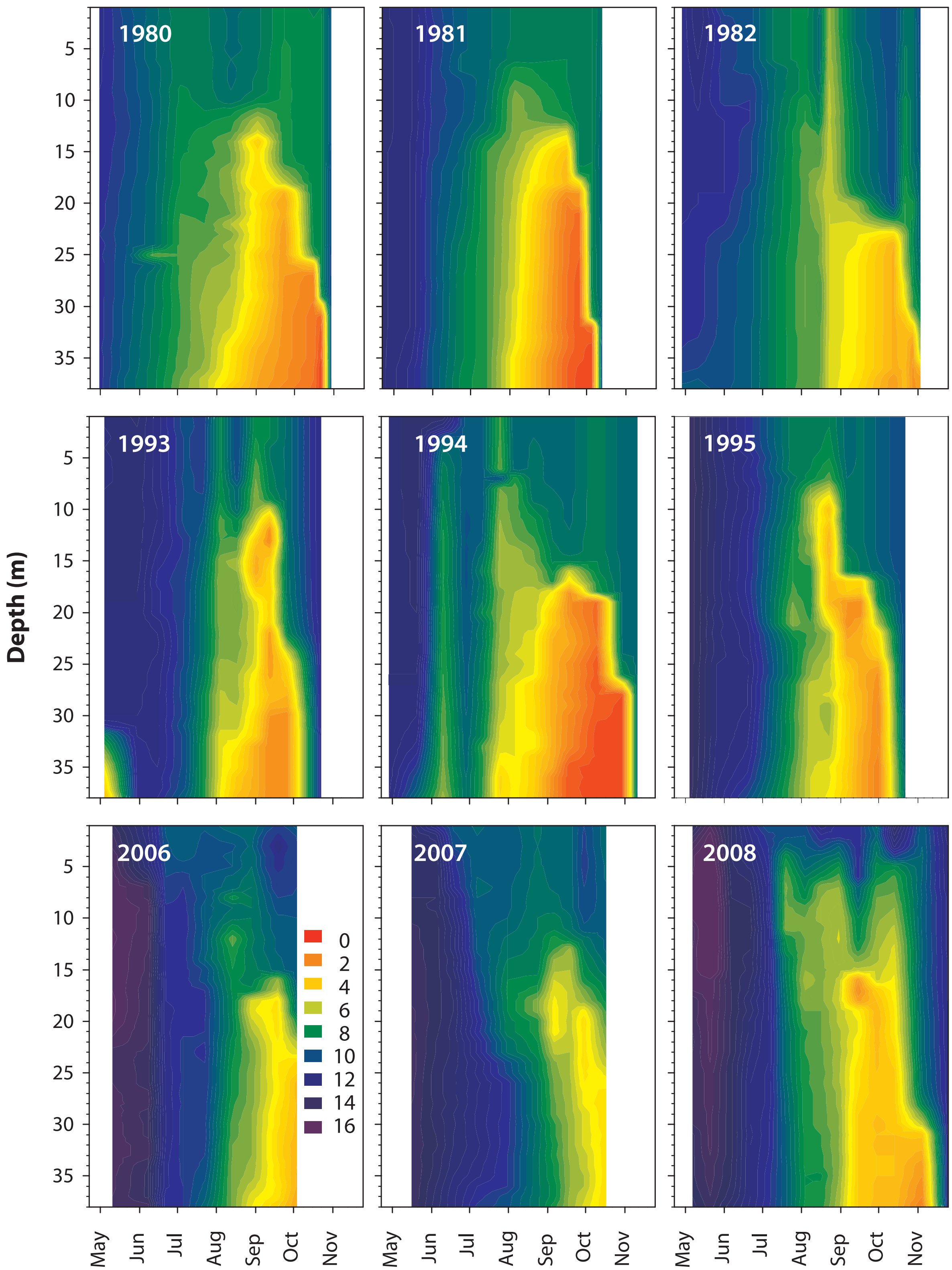

Watermilfoil near Thorah Island © LSRCA



In 2008, the LSRCA conducted a macrophyte survey of Lake Simcoe at depths ≤ 20 m, and found that macrophyte abundance was positively correlated with shallower depths and with the presence of fine-grained sediments (B. Ginn, personal communication). Macrophyte abundance is greater near tributary outlets, which are sources of nutrients. Because large areas of the main basin and Cook's Bay are very shallow, a considerable proportion of the lake supports macrophyte growth. No lakewide historical macrophyte surveys exist to assess changes in abundance over time; however, comparison with surveys in Cook's Bay during the 1980s indicate that macrophyte growth there has increased substantially. The apparent increase in macrophyte abundance likely resulted from increased water clarity during the 1990s.

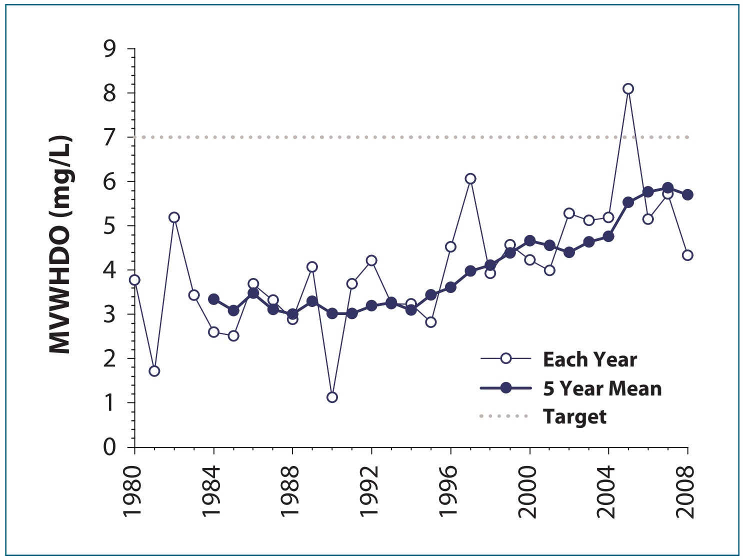
Dissolved Oxygen

Upon stratification, the cool bottom waters of the hypolimnion contain a maximum concentration of dissolved oxygen (DO). As the summer progresses, DO is slowly consumed by organic matter decomposition (primarily algae) and chemical transformations occurring at the sediment-water interface, and not until fall overturn does a fresh source of oxygenated water reach the deeper parts of the lake. Throughout the 1980s, DO concentrations measured at the lake bottom decreased to 2 mg/L or lower



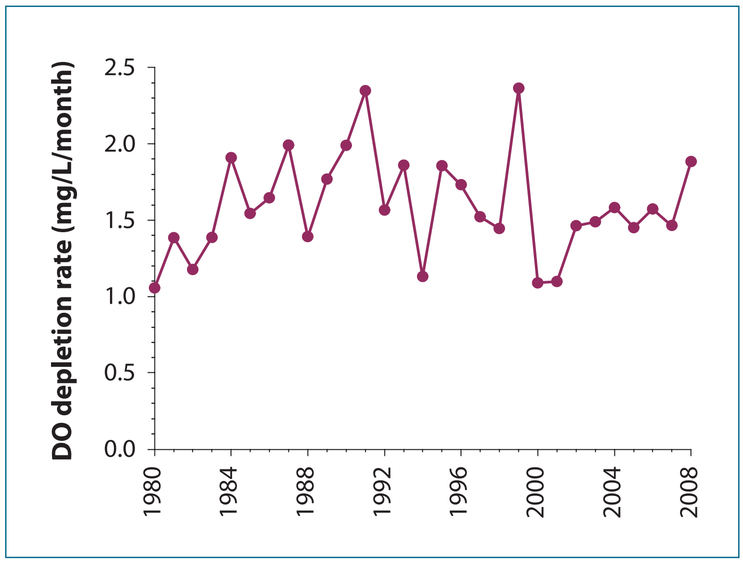
Dissolved oxygen (mg/L) profiles at station K42 over six summers. Red contours indicate oxygen depletion (< 2 mg/L). Note: when data collection started and ended differed each year.

Ice huts on Lake Simcoe



Minimum volume-weighted hypolimnetic dissolved oxygen at station K42.

in most years (red areas in figure). In the mid 1990s, conditions improved although measured DO concentrations still fell below 2 mg/L in some years. In the most recent years the same extent of oxygen depletion is not seen (although sampling in 2006 and 2007 did not extend to fall overturn). DO is reported here for station K42, which is located in Kempenfelt Bay at the deepest part of Lake Simcoe (maximum depth 40 m) where optimal habitat for coldwater fish occurs.



Monthly dissolved oxygen depletion rate at station K42 adjusted to 4 °C

To sustain the recruitment of Lake Simcoe's coldwater fish population, a minimum end-of-summer volume-weighted DO concentration of 7 mg/L in the hypolimnion has been set as the target in the LSPP. This value was estimated for station K42 as either the lowest measured volume-weighted DO concentration from 18 m to the bottom before September 15 or was interpolated for September 15 from a linear depletion rate, whichever was less. September 15 is the chosen cut-off day since, although DO concentrations continue to decrease past this day, surface temperatures also have decreased allowing coldwater fish to be higher in the water column where oxygen concentrations are sufficient. The adequacy of this date for protecting coldwater fish habitat will continue to be re-assessed in light of observed increases in stratification periods. Minimum volume-weighted hypolimnetic DO (MVWHDO) at K42 increased significantly over the period 1980–2008. During the 1980s, MVWHDO concentrations remained well below the proposed 7 mg/L target and were less than 2 mg/L in some years. MVWHDO concentrations increased progressively during the 1990s and 2000s, although the 5 year running average has remained below the 7 mg/L minimum target. In contrast, there has been no significant change in DO depletion rates over the past thirty years. With stratification occurring earlier in the spring and lasting longer into the fall, more oxygen should be consumed by the end of summer if the same depletion rate exists. Because MVWHDO concentrations are exhibiting an increasing trend, it suggests that greater oxygen saturation exists when the hypolimnion forms in the spring.

Relating Dissolved Oxygen to Phosphorus Loads

Lake Management Objectives

- One of the main objectives of the LSPP (and previous lake management strategies) is to maintain hypolimnetic DO concentrations above a minimum level to provide suitable habitat for coldwater fish populations. The LSPP has set a minimum end-of-summer hypolimnetic DO target of 7 mg/L.
- The other main objective of the LSPP is to reduce total P loads to the lake to achieve the DO target.
- The two objectives are linked through a series of relationships connecting nutrient inputs, algal growth and dissolved oxygen depletion, and are estimated using the empirical model developed by Nicholls (1997).

1		2		3		4
P loads	►	P concentrations	►	chlorophyll *a* concentrations	►	dissolved oxygen

How are these relationships connected?

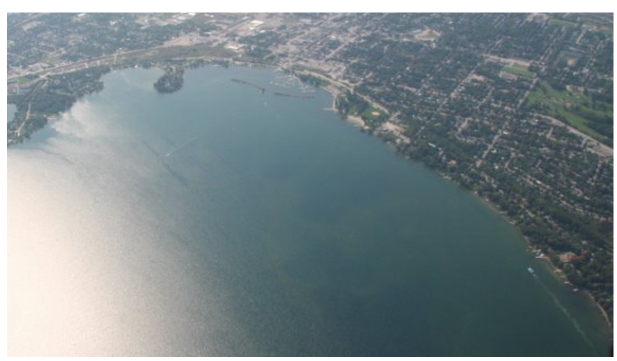
1 ► 2 The amount of total P entering the lake is the main driver of total P concentration in the lake. This relationship is also dependent on the rate of total P loss at the outflow and retention in the sediments (Nicholls 1997).

2 ► 3 P is the primary limiting nutrient in freshwater lakes (Schindler 1977). Spring volume-weighted total P concentrations are a good predictor of summer chlorophyll *a* (algae) concentrations (Dillon and Rigler 1975; Smith and Shapiro 1981), although correlations may not exist for all seasons due to changing light and temperature conditions and consumption of algae by zooplankton.

3 ► 4 Microbial breakdown of algal biomass at the bottom of the lake is the main process consuming oxygen. Hypolimnetic DO depletion rates are highly related to chlorophyll *a* concentrations (Vollenweider and Janus 1982). While chemical transformations in lake sediments (such as iron oxidation) also require oxygen, the amounts consumed in these reactions are much less.

What about other issues?

P and DO are the two main priorities in the restoration and protection of Lake Simcoe, but they are not the only concerns being addressed; pathogens, pollutants, invasive species and other issues are part of ongoing protection, research and monitoring initiatives.

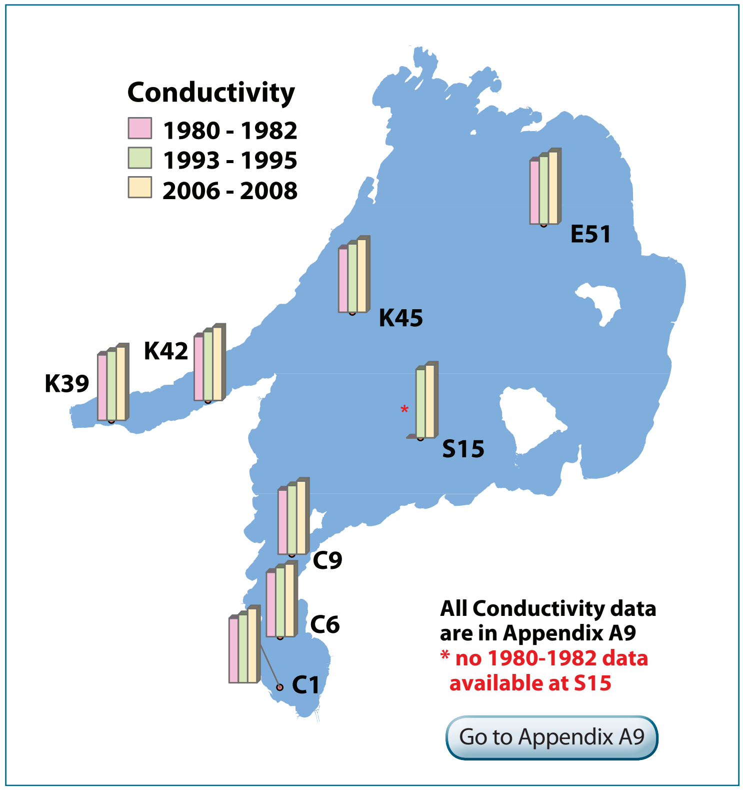


Orillia at the south end of Lake Couchiching. Credit: Nick Wilson

Chloride, metals and organic contaminants

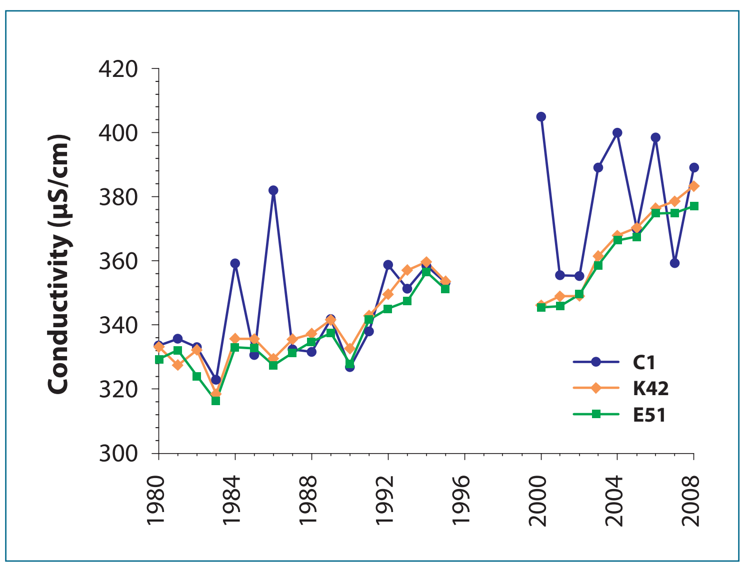
Chloride, Sodium and Conductivity

Over the past three decades there have been significant increases in conductivity at the lake stations, as well as in chloride concentrations at the WTP intakes and the lake outflow. Chloride and sodium concentrations also increased at the lake stations, although trend analysis was not possible because levels were measured inconsistently at these sites in earlier years. Chloride concentration at the outflow has increased from 11 mg/L in 1971 to 40 mg/L in 2008, and is increasing at a faster rate than in the past.



Conductivity 29 year trends and recent averages (± stdev)

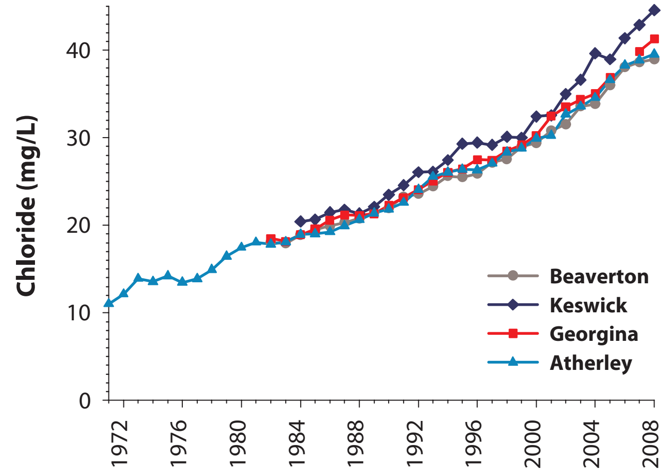
	1980–2008 Trend	2004–2008 Average (µS/cm)
C1	↑	384 (39)
C6	↑	375 (10)
C9	↑	375 (8)
K39	↑	377 (9)
K42	↑	375 (8)
K45	↑	372 (13)
E51	↑	372 (7)
S15	↑	373 (8)



Conductivity at three lake stations.

Chloride trends over 27 years and recent averages (± stdev) at WTP intake pipes and Atherley outflow

	1982–2008 Trend	2004–2008 Average (mg/L)
Beaverton	↑	37.1 (2.8)
Keswick	↑	41.6 (3.7)
Georgina	↑	38.2 (1.4)
Atherley	↑	37.5 (2.6)



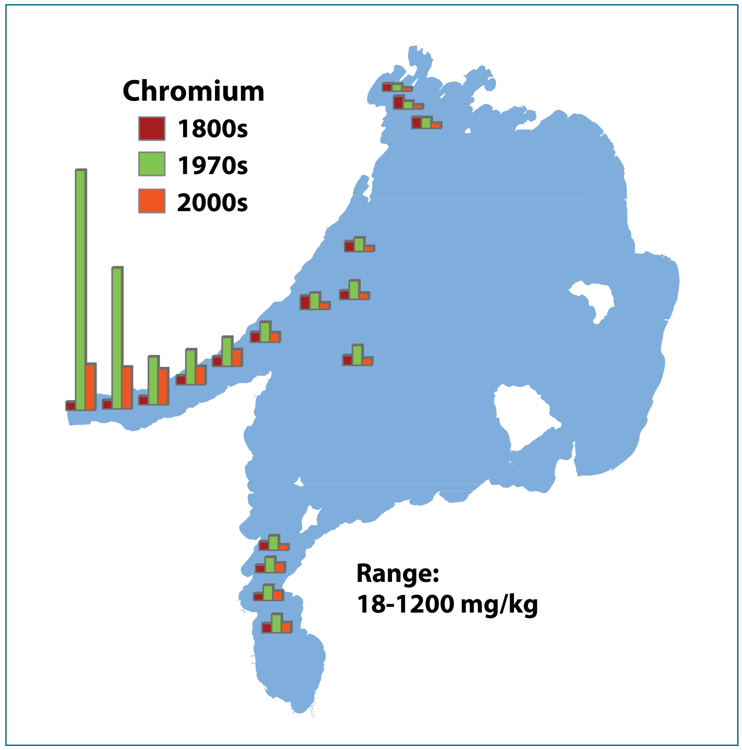
Chloride annual concentrations at WTP intake pipes and Atherley outflow

Chloride concentrations at the WTP intake pipes show seasonal variability and are generally highest between December and March. The increase in chloride concentration demonstrates the effects of increasing impervious surface area within the basin, and similar trends are found across cold climate areas in Canada and United States (Smith et al. 1987). Although Lake Simcoe is a large lake situated in a basin with a relatively small proportion of urban land use (6.7%), decades of road salt application in the basin have altered the lake's water chemistry. Within the lake, chloride concentrations are still below the draft Canadian Water Quality Guideline for freshwater of 128 mg/L; however, salt inputs from the basin may cause detrimental ecological effects such as increased heavy metal export and changes in the composition of the lake's biological community, and may even alter lake water density, affecting lake mixing. Chloride, sodium and conductivity will continue to be monitored in the lake. Actions proposed in the LSPP to control or reduce urban stormwater runoff will likely reduce inputs in the future. Road salts containing inorganic chlorides have also been designated as toxic under the Canadian Environmental Protection Act. Although there are no specific actions proposed for managing the risks associated with road salts containing chloride, a code of practice for their environmental management has been developed to manage risks posed to the environment (Environment Canada 2004).

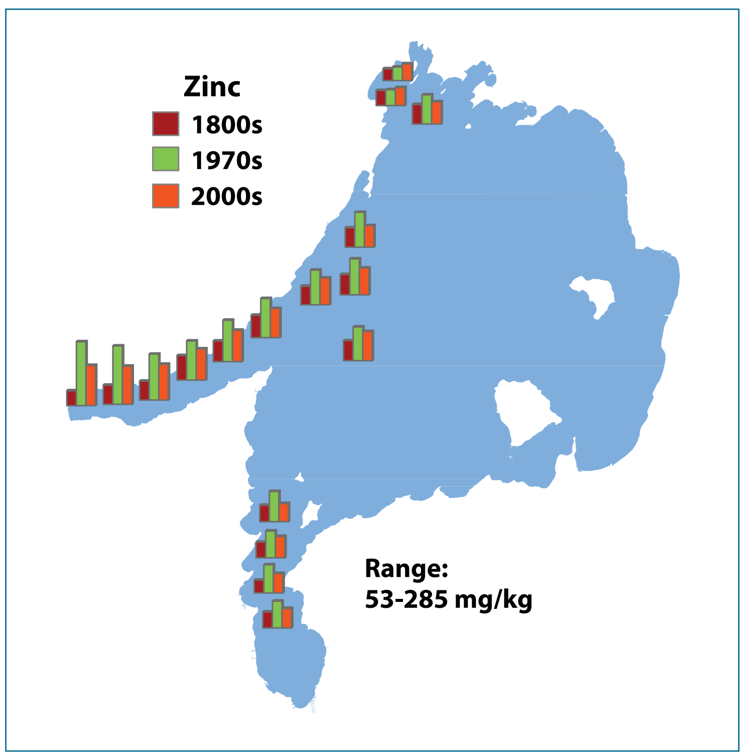
West Holland River in the center of Holland Marsh. Credit: Nick Wilson

Metals and Organic Contaminants

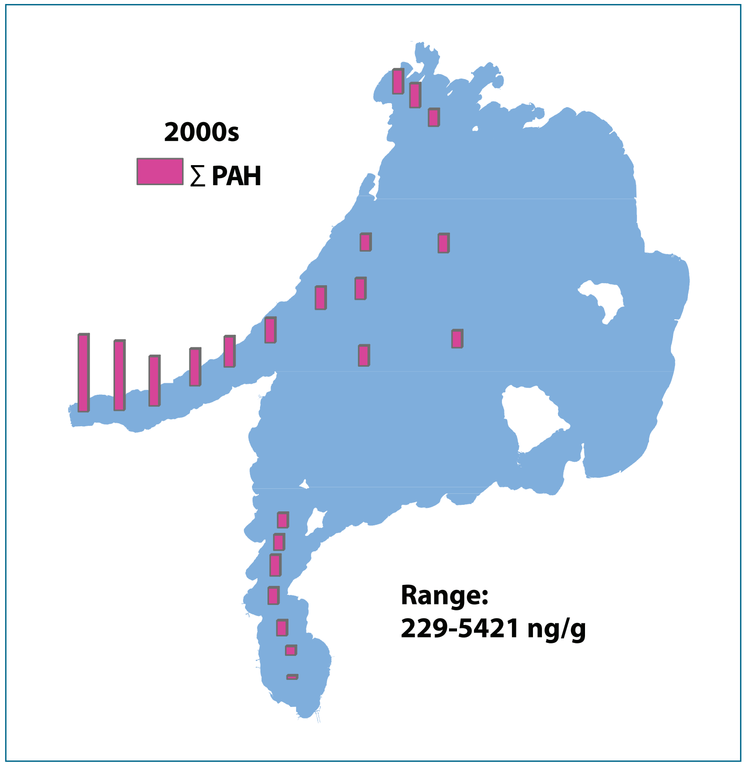
Other pollutants of concern outlined in the LSPP include metals and organic contaminants. Concentrations of these are typically very low in lake water due to processes that remove dissolved compounds and particulates from the water column to the lake sediments. A sediment survey was conducted in 2008 in Lake Simcoe to measure current and historic levels of metals and organic contaminants. The highest concentrations of metals were found in Kempenfelt Bay sediments due to enrichment from urban and industrial sources, and decreased along a west to east gradient (Landre et al. submitted). Metal concentrations of historical concern (e.g., Chromium) have decreased from peak levels, although are still much higher than background (pre-1800) concentrations. These reductions are a result of improved wastewater treatment and changes in industrial activity. However, metals typically found in uncontrolled urban stormwater run-off (e.g., Zinc) remain at elevated concentrations.

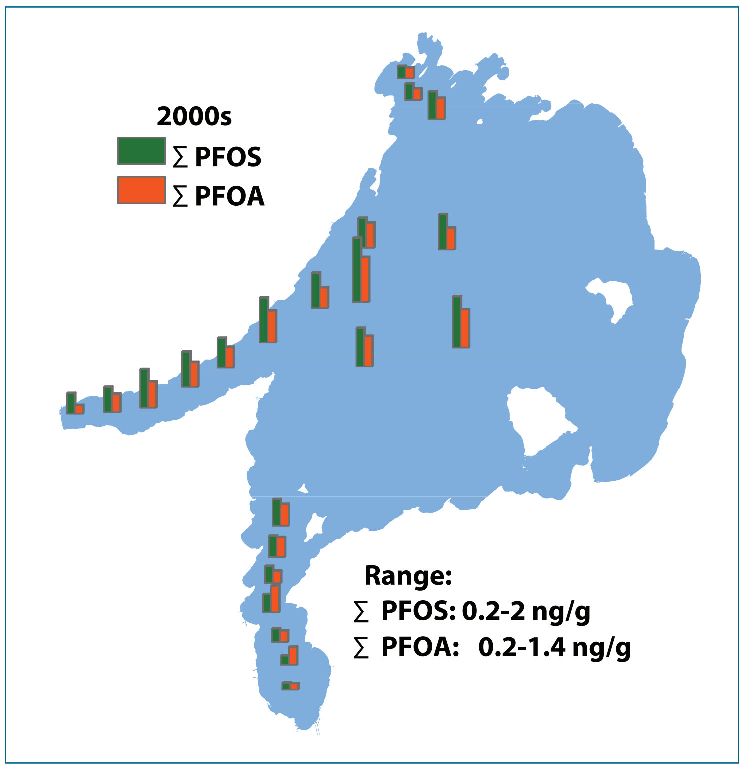


Box Corer after deployment in Cook's Bay while sediment sampling. Credit: Benoit Lalonde, Environment Canada



Sediment cores inside the Box Corer.
Credit: Benoit Lalonde, Environment Canada



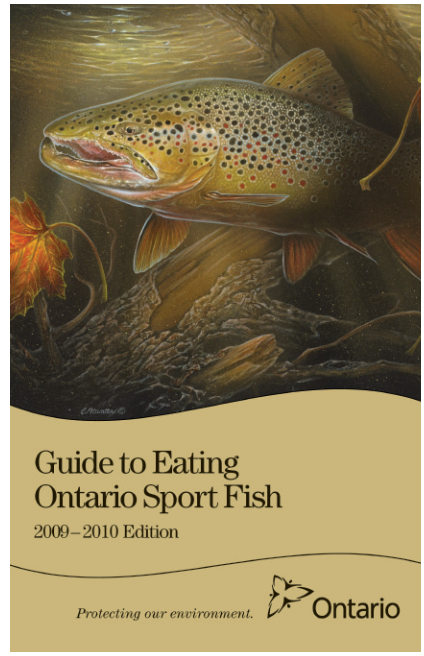


Organic chemicals that were assessed in the 2008 sediment survey include polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) (Helm et al. submitted). PCBs were used in electrical transformers and building sealants among other applications, but are being replaced in transformers under regulation and as buildings are renovated. PAHs are a by-product of the burning of fuels and are also present in coal tar products such as asphalt and roofing tar. PCBs and PAHs have declined from peak concentrations observed in 1970 and the late 1950s, respectively, although are still above pre-industrial levels. Current concentrations of PCBs and PAHs are greatest in Kempenfelt Bay, reflecting past emissions and recent residual inputs from the Barrie area.

Recently, attention has been directed towards other persistent organic chemicals that have been widely used as flame retardants and surface active agents. The polybrominated diphenylethers (PBDEs) have been used in furniture foam, fabrics and plastics to prevent the spread of fire. The perfluorinated chemicals, such as perfluorooctane sulfonate (PFOS) and acid (PFOA), have been used to provide stain resistance to carpets and fabrics, and in the production of polymers. Current sediment concentrations of both of these classes of chemicals were more evenly distributed across Lake Simcoe than the PCBs and PAHs. This may indicate that inputs from

sources outside of the watershed, resulting from their widespread use in the populated regions of Southern Ontario, are just as important as direct inputs from urban centres within the watershed. PBDE levels have increased over the past two decades; however, this is expected to change in coming years as some PBDEs have been withdrawn from the market and others are coming under regulation.

Based on Ontario's sport fish contaminant monitoring data used in the Guide to Eating Ontario Sport Fish (www.ontario.ca/fishguide), levels of contaminants such as PCBs, DDT, and dioxins and furans in sport fish (e.g., lake trout, walleye and lake whitefish) have decreased or remained stable over the last 10 to 15 years. Levels of these contaminants in Lake Simcoe fish are generally equal to or lower than levels found in Great Lakes fish. However, mercury levels in lake whitefish from Lake Simcoe have actually increased slightly, possibly due to changes in lake food web structure (Gewurtz et al. submitted).

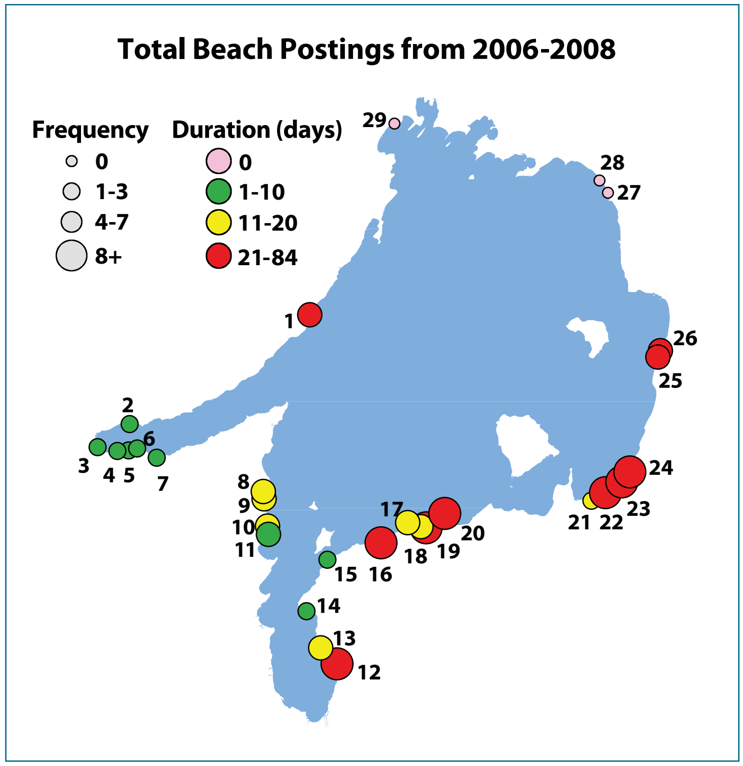


Pathogens

Pathogens are an important water quality issue because they present a concern to human health. Beaches are routinely monitored for *Escherichia coli*, an indicator of fecal pollution and presence of pathogens (bacteria, protozoa and viruses). Sources of pathogens include sewage spills, leaking septic systems, discharge from boats, animal waste from urban and agricultural runoff, and birds and other animals present at the beach. Beach sand has also been found to harbour bacteria including *E. coli* (Whitman and Nevers 2003). Factors that promote high bacterial counts at beaches include rainfall and onshore winds.

On Franklin Beach looking west

Beaches are sampled from June through to August by the Durham, Simcoe and York Health Units. Beaches are posted with swimming advisories when geometric mean concentrations of *E. coli* exceed 100 cfu/mL, or when other adverse conditions occur, and remain posted until laboratory results show that bacteria levels are safe. Data presented here are the total number of postings and the total number of days that beaches were closed from 2006 to 2008. During this time, most beaches had at least one posting or closure; only three beaches at the north end of the lake remained posting-free. Advisories were rarely posted in Kempenfelt Bay, although all six beaches were pre-emptively closed for one day in 2006 after a major sewage spill occurred. Beaches along the south and east shore of the main basin were closed most frequently and for the longest duration. Beaches in Durham (numbers 24, 25 and 26 on the map) are only sampled weekly, which could result in longer postings at these locations. Irrespective of duration, the higher total number of postings along the south and east shores may be due to a greater tendency for onshore wind direction, more sources of bacteria or a combination of both.



1 Memorial Park Beach
2 Johnson's Beach
3 Barrie Centennial Park Beach
4 Minet's Point Beach
5 Gable Place
6 Tyndale Beach
7 Wilkins Beach
8 Leonard's Beach
9 Glenwood Beach
10 Alcona Beach North
11 Alcona Beach South
12 Claredon Beach
13 Keswick Beach
14 Balfour Beach
15 Island Grove Beach
16 Willow/Paradise Beach
17 Willow Wharf Dock
18 Franklin Beach
19 De La Salle Beach
20 Jackson's Point Beach
21 Holmes Point Beach
22 Peninsula Motel Beach
23 Port Bolster Beach
24 Thorah Centennial Beach
25 Beaverton Beach South
26 Beaverton Beach North
27 The Steps
28 Lagoon City Beach
29 Kitchener Beach

Recreation on Lake Simcoe. Credit: Nick Wilson

Invasive Species

Alkalinity trends over 29 years and recent averages (± stdev)

	1980–2008 Trend	2004–2008 Average (mg/L)
C1	↓	113 (12)
C6	↓	114 (4)
C9	↓	115 (3)
K39	↓	116 (3)
K42	↓	116 (3)
K45	↓	116 (3)
E51	↓	116 (3)
S15	↓	116 (3)

Zebra mussels

Zebra mussels covering the bottom of one of the locks of the Trent-Severn Waterway. Credit: Jim Eddie.

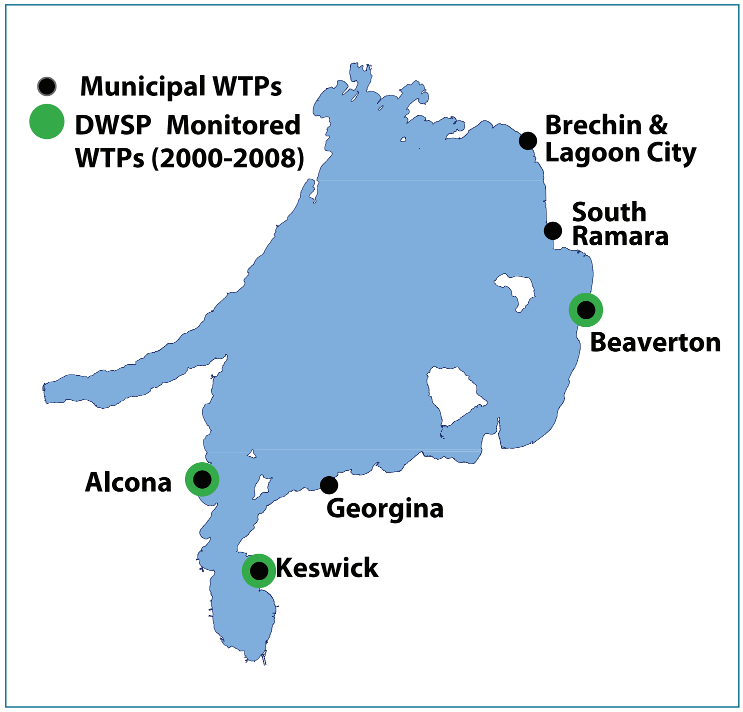
Invasive species can have extensive impacts on the physical, chemical and biological features of lake ecosystems. One species that has had such an impact is zebra mussels, which invaded Lake Simcoe in 1994. Due to their rapid, widespread establishment and high filter feeding capacity, they have possibly impacted water quality in Lake Simcoe in numerous ways, such as causing increased water clarity, reduced algal biovolumes, and lower alkalinity and calcium concentrations. Zebra mussels are also thought to affect P cycling in lakes by converting particulate-bound P to more reactive forms and by increasing P concentrations in the nearshore zone they inhabit, a phenomenon known as the nearshore shunt (Hecky et al. 2004). Whether this is occurring in Lake Simcoe is currently being researched.

Eurasian watermilfoil invaded the lake in 1985 and is currently one of the most abundant macrophytes present in the lake. It is among the most troublesome invasive species in freshwater lakes across North America. Problems associated with it are interferences with swimming and fishing, reduced DO concentrations and increased mosquito populations (Smith and Barko 1990). Watermilfoil can grow into dense stands and can replace weedbeds of native species (Madsen et al. 1991).

Other species that have invaded Lake Simcoe include several species of fish (common carp, rainbow smelt, bluegill, black crappie, round goby), zooplankton (spiny waterflea), crayfish (rusty crayfish) and another macrophyte (curly pondweed). To protect the lake ecosystem from invasive species, the LSPP recommends that further invasions must be prevented. Research on invasive species (e.g., zebra mussels and the spiny waterflea) in the lake is underway.

A Source of Drinking Water

Lake Simcoe is used as a water source by six municipal residential drinking water treatment plants (WTPs) that serve more than 55,000 residents (Drinking Water Information System, July 23 2009). Drinking water quality is tested regularly at each of these systems as specified by the Ontario Drinking Water Systems Regulation (O. Reg. 170/03). According to the Chief Drinking Water Inspector's Annual Report (2005–2006, 2006–2007, 2007–2008; available at www.ontario.ca/drinkingwater) the drinking water from these six Lake Simcoe WTPs is of high quality.



Lake Simcoe drinking water quality summarized from the Chief Drinking Water Inspector's Reports

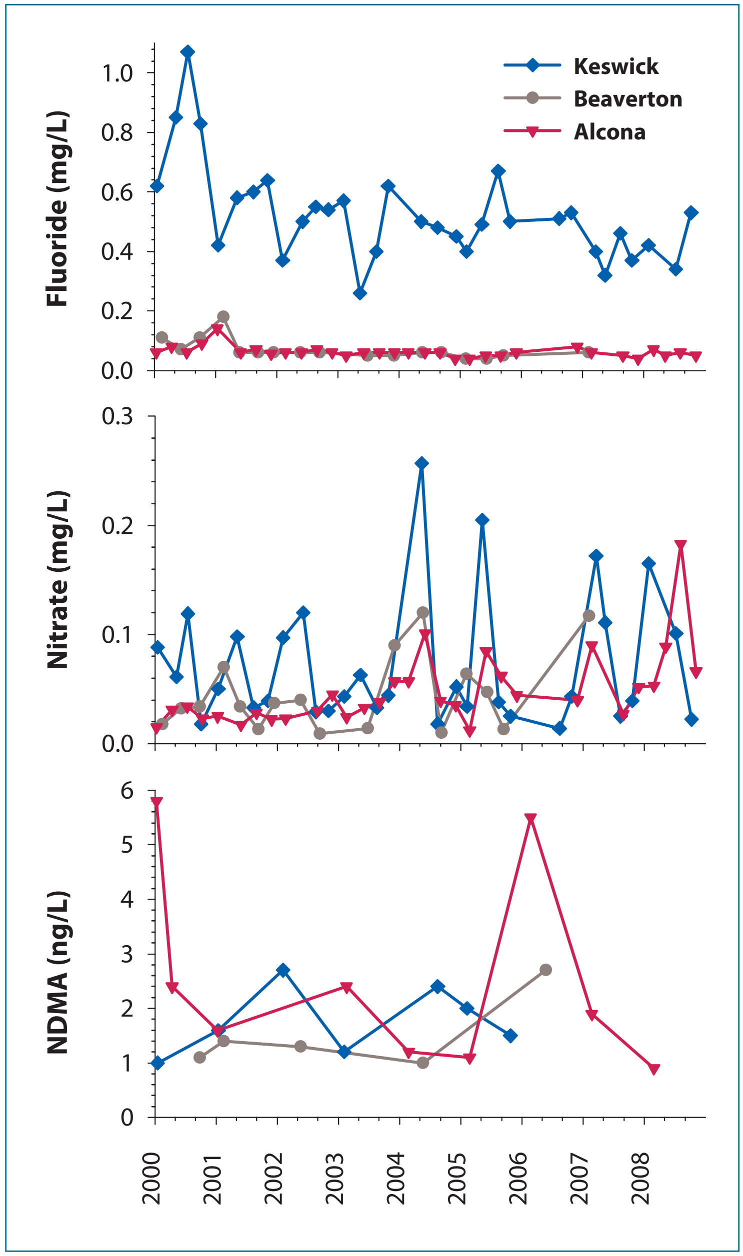
	Percent of tests meeting standard		
	2005–2006	2006–2007	2007–2008
Beaverton WTP	97.4	100	100
Keswick WTP	100	100	99.7
Georgina WTP	100	100	100
Alcona WTP	99.8	100	99.8
Brechin and Lagoon City WTP	100	100	99.4
South Ramara WTP	100	100	100

In addition to meeting their regulated monitoring requirements, owners of three of Lake Simcoe WTPs also participate in the Drinking Water Surveillance Program (DWSP), a voluntary monitoring program that has been operated by the Ministry in cooperation with municipalities since 1986 (http://ontario.ca/dwsp). Owners of Alcona, Beaverton and Keswick WTPs have participated since 2000 or earlier; however, Beaverton left DWSP in 2007 while Georgina joined in 2009. Water samples are collected approximately 4 times per year and are analyzed for over 250 water quality parameters, some of which have Ontario Drinking Water Quality Standards (ODWQS), whether health-related or aesthetic objectives, or operational guidelines. Three parameters that did not meet the health-related ODWQS at DWSP monitored WTPs elsewhere in the province were selected as indicators of drinking water quality for this report. These parameters from the treated

drinking water of three Lake Simcoe WTPs were summarized over the period 2000–2008.

Fluoride is a chemical substance that may be present in source water as a result of the erosion of natural deposits or discharge from fertilizer and aluminium factories but also may be added to water during the treatment process to promote strong teeth. Of the three WTPs, only Keswick adds fluoride and, for this reason, fluoride levels were higher there than in the other two systems. From 2000–2008, results remained stable at Alcona and Beaverton but showed a general decrease at Keswick. All results met the ODWQS of 1.5 mg/L.

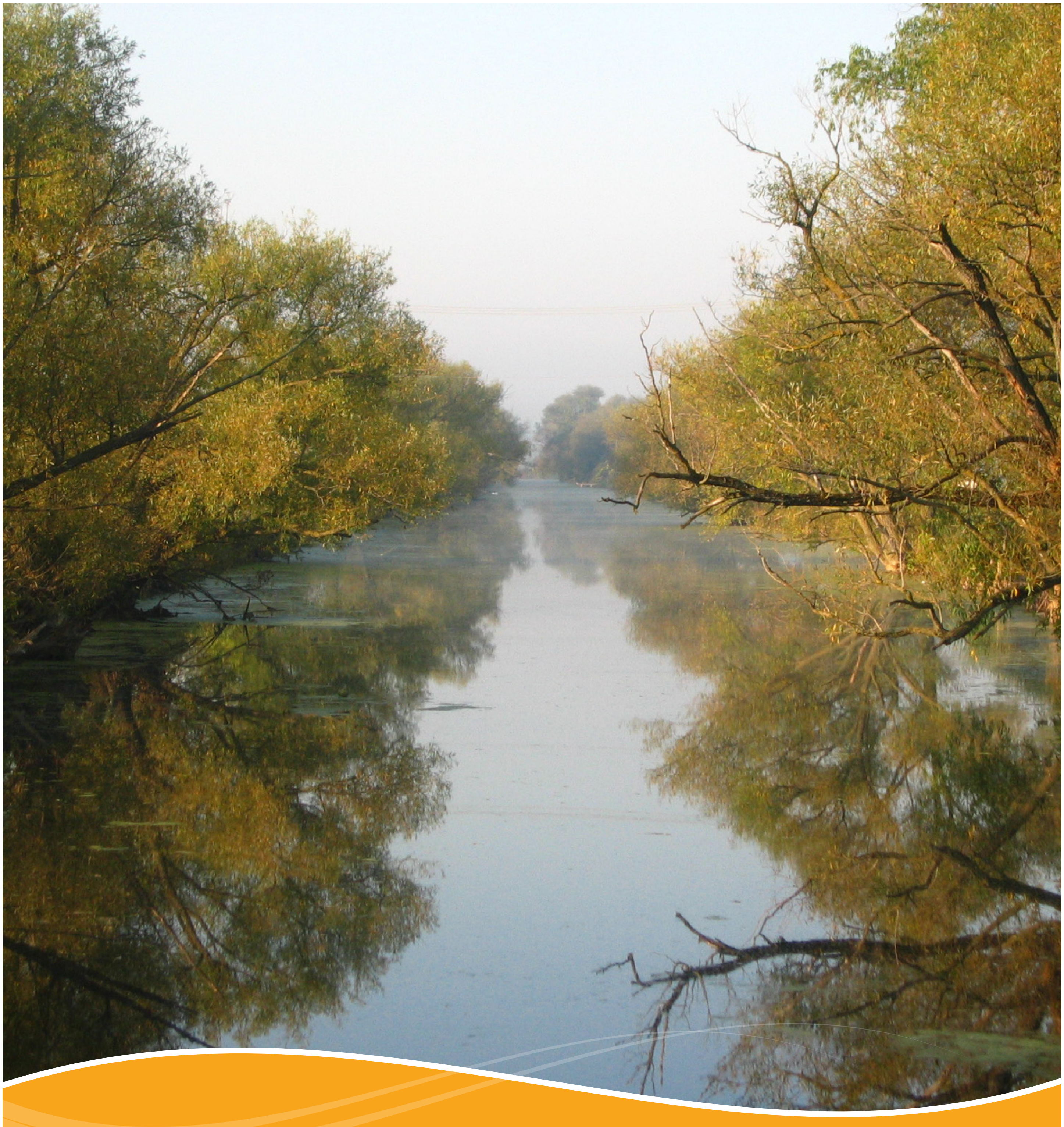
Nitrate is present in source water generally as a result of runoff from fertilizer use, leaching from septic tanks, sewage and erosion from natural deposits. Of the 81 treated drinking water samples analyzed, all nitrate results met the ODWQS of 10 mg/L, with the highest concentration being 0.257 mg/L. For most years in this period, nitrate levels are higher at Keswick than other plants. At Alcona and Beaverton, levels have increased slightly but remain low.



Fluoride, nitrate and N-nitrosodimethylamine concentrations at three DWSP monitored WTPs. On the NDMA figure, only detected results and maximum daily values are shown.

Although seldom used industrially today, N-nitrosodimethylamine (NDMA) was once used as an antioxidant in lubricants and a solvent in the fibre and plastic industries. It is an impurity that is produced during the manufacture of rocket fuels, a by-product of the manufacture of certain pesticides, and it has been found in cosmetics, detergents and food such as cured meats, smoked fish, tobacco and alcohol. NDMA was only detected in 26 of the 54 treated drinking water results that were analyzed and all results met the ODWQS of 9 ng/L.

Under the 2006 Clean Water Act, issues and potential threats to Lake Simcoe as a source of drinking water are being assessed by the LSRCA in support of the local Source Protection Committee generated assessment report. This assessment will lead to a source protection plan that will prevent future impacts and address identified issues.



North Holland Canal in early autumn. Credit: Jim Eddie

Chapter 4
Ongoing and Future Work

chapter four

Lake Simcoe has experienced some improvements in water quality over the past three decades, but continued efforts towards lake restoration are required. P concentrations at some of the lake stations decreased in the 1980s but there has been little decline in recent years. Phytoplankton biovolumes have also decreased slightly or remained the same over this time, and the problematic cyanobacteria and green algae are less abundant. Water clarity has improved substantially as evidenced by 30 to 50% increases in Secchi disk depth. The increased water clarity is in part due to reduced P concentrations and corresponding decreases in algal abundance, and with the establishment of the filter-feeding zebra mussels. Macrophyte biomass has increased in Cook's Bay and is most dense near tributary outlets. Minimum end-of-summer deep water dissolved oxygen concentration has significantly improved since the 1980s, but currently does not meet the proposed 7 mg/L DO target. The duration of stratification in Lake Simcoe has lengthened over the past three decades at the deepest part of the lake, starting 20 days earlier in the spring and ending 15 days later in the fall. Chloride concentrations are increasing in the lake while metals and organic contaminants in lake sediments have generally decreased, although are currently still above pre-industrial levels. These stressors and others (e.g., invasive species and pathogens) that impact lake ecology and may impede lake restoration efforts will continue to be monitored. Lastly, Lake Simcoe provides a high quality source of drinking water for six communities.

To support the initiatives in the LSPP, Lake Simcoe research and monitoring is being enhanced. Two historical lake sampling stations, which were sampled until 1999, are being restored for a total of 10 lake sampling locations starting in 2009, and analysis of all monitored parameters will be continued. Current collaborative research and modelling work includes studies on the atmospheric deposition of P, zooplankton biomass and community composition, the nearshore P shunt, ecological target setting, nutrient bioavailability, modelling P loading and deep water oxygen dynamics, and paleolimnological assessments of eutrophication, macrophytes, and dissolved oxygen levels and fish abundance. The results of the research and monitoring will inform actions and targets identified in the LSPP and measure progress towards lake protection and restoration.

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- JDE Ventures (Jim Eddie)
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- Durham Region Health Unit
- Simcoe County Health Unit
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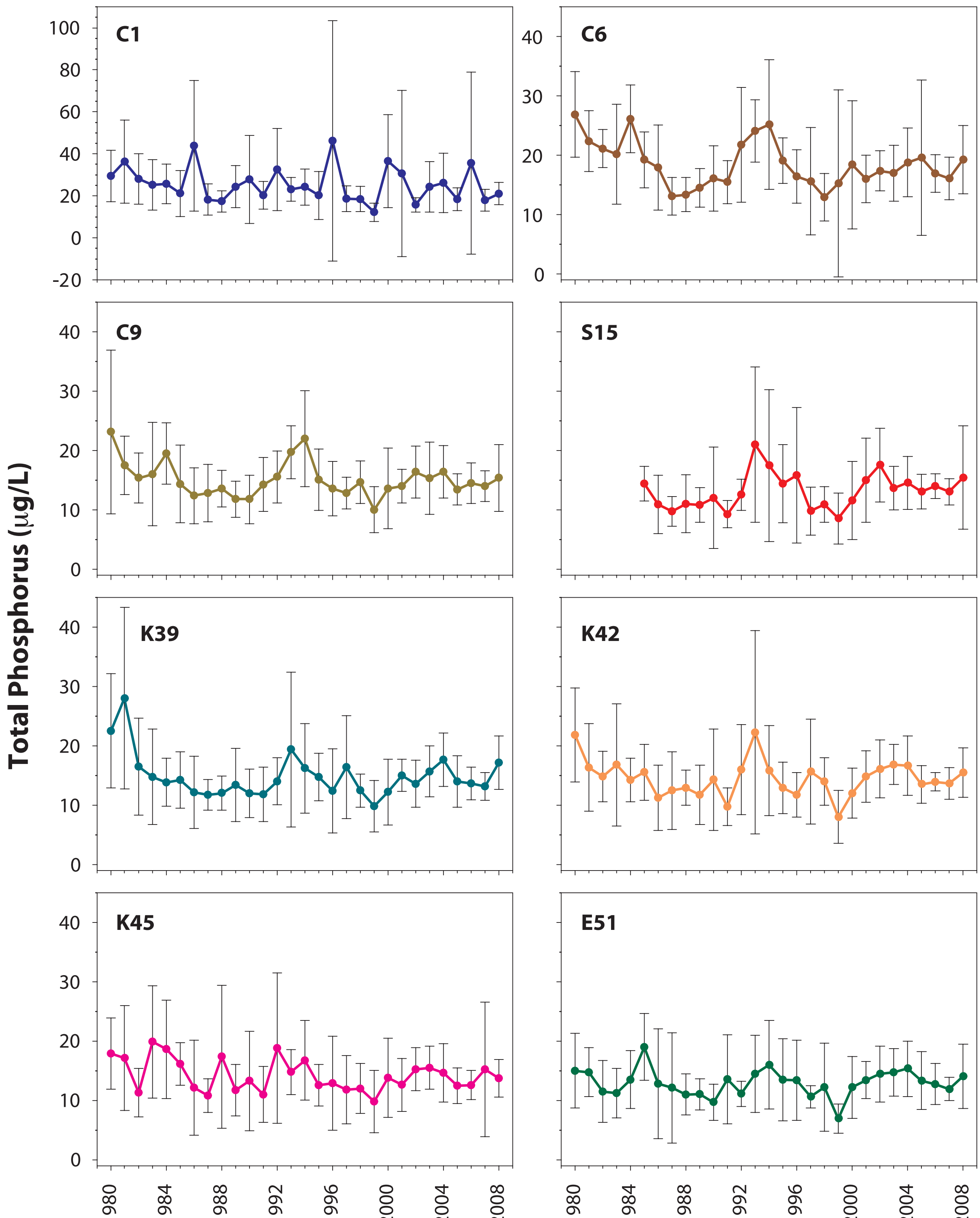
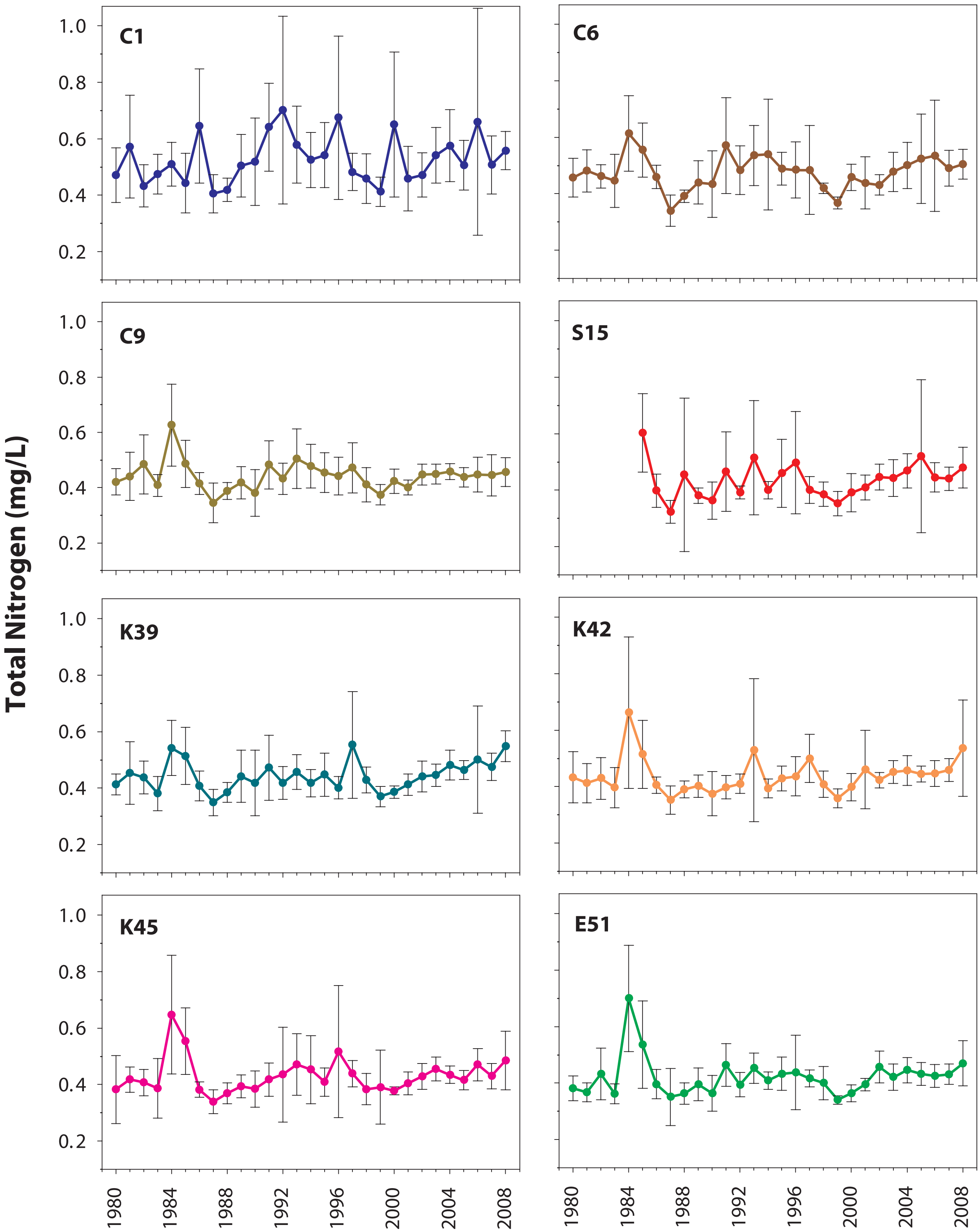
APPENDIX

A1 Total phosphorus concentrations at all 8 lake stations. Values for each year are an average (± stdev) of ice-free (May–Oct) concentrations. Note that the y-axis scale for C1 is approximately three times larger than the other stations.



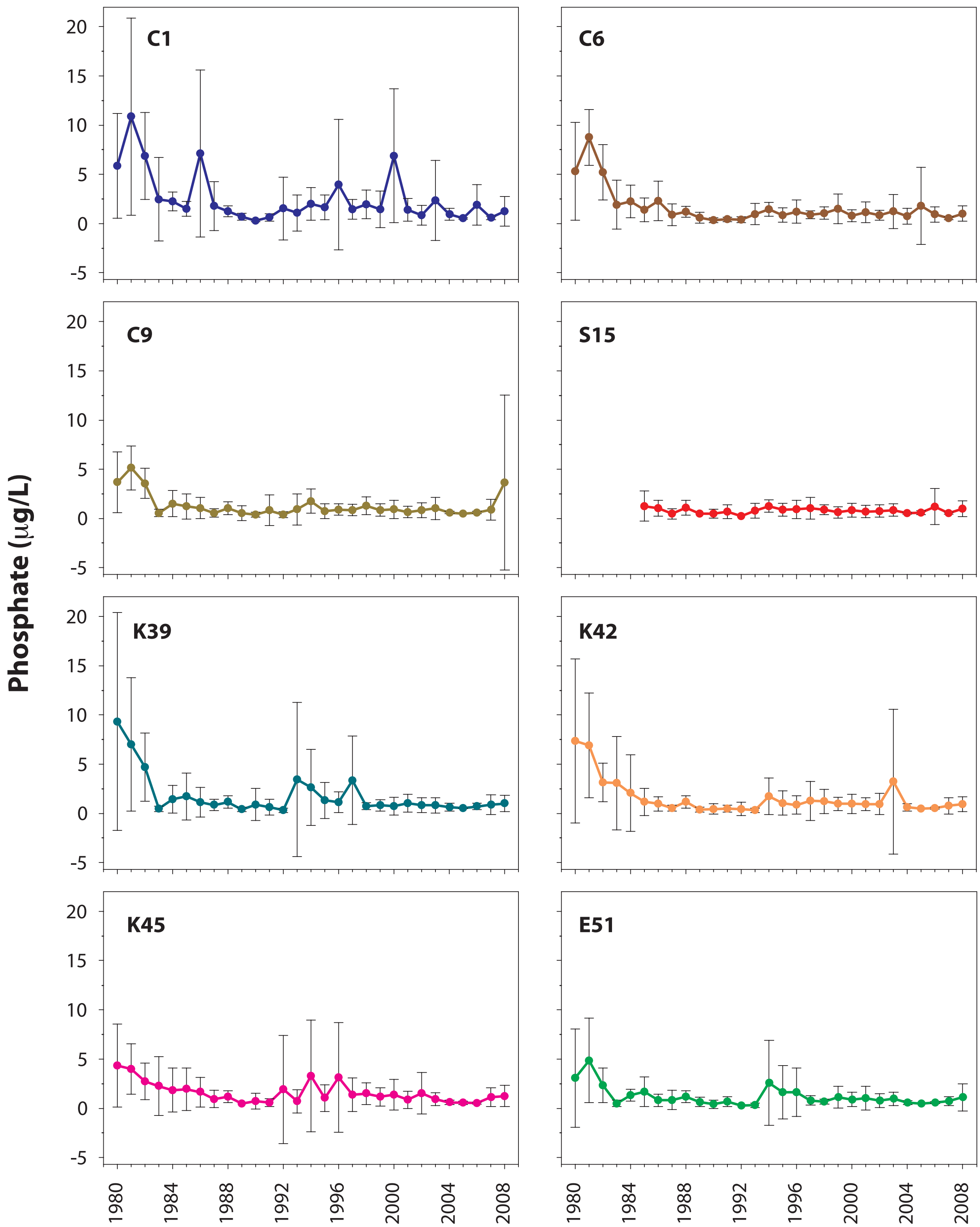
Back to Phosphorus section

A2 Total nitrogen concentrations at all 8 lake stations. Values for each year are an average (± stdev) of ice-free (May–Oct) concentrations.



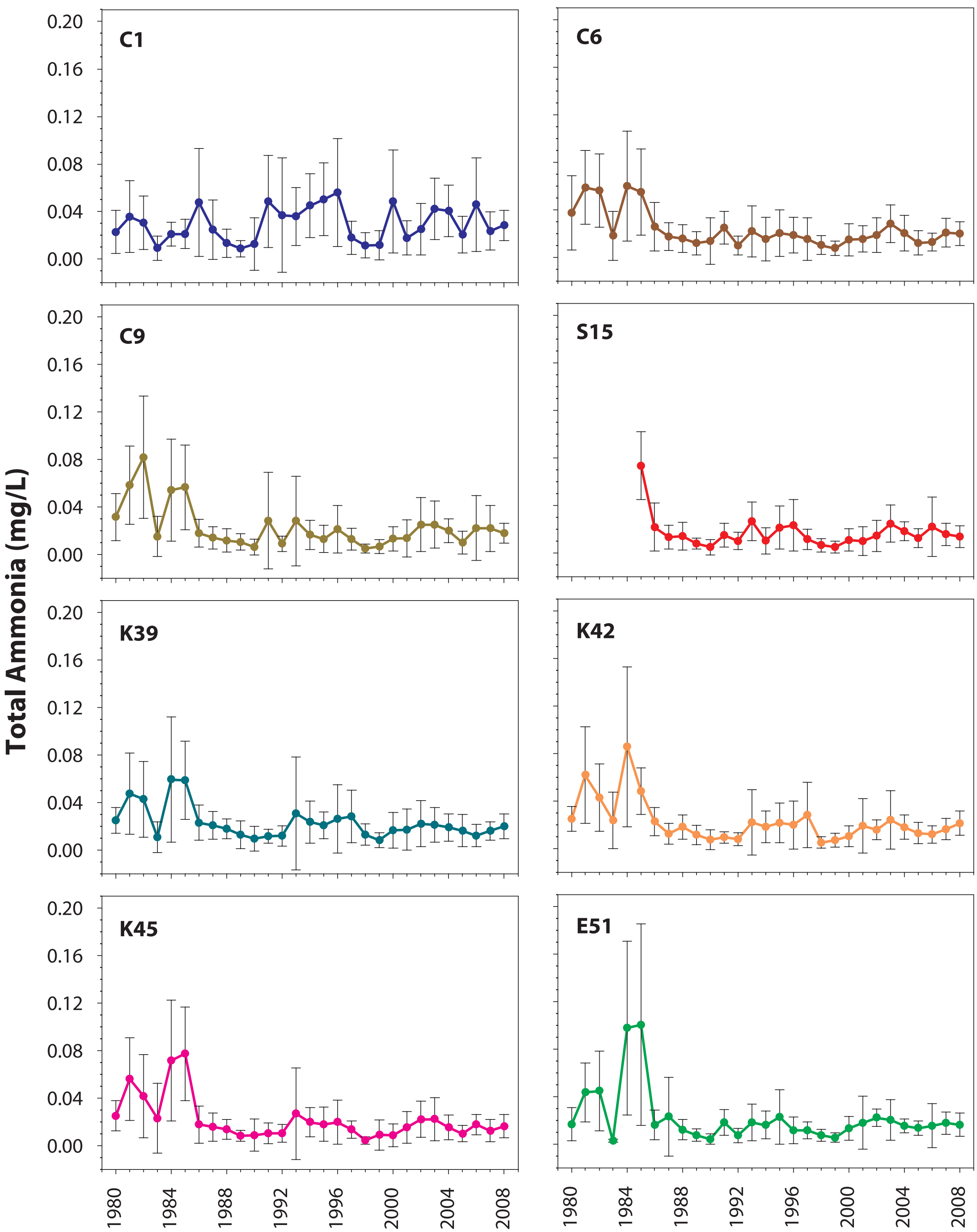
Back to Nitrogen section

A3 Phosphate concentrations at all 8 lake stations. Values for each year are an average (± stdev) of ice-free (May–Oct) concentrations.



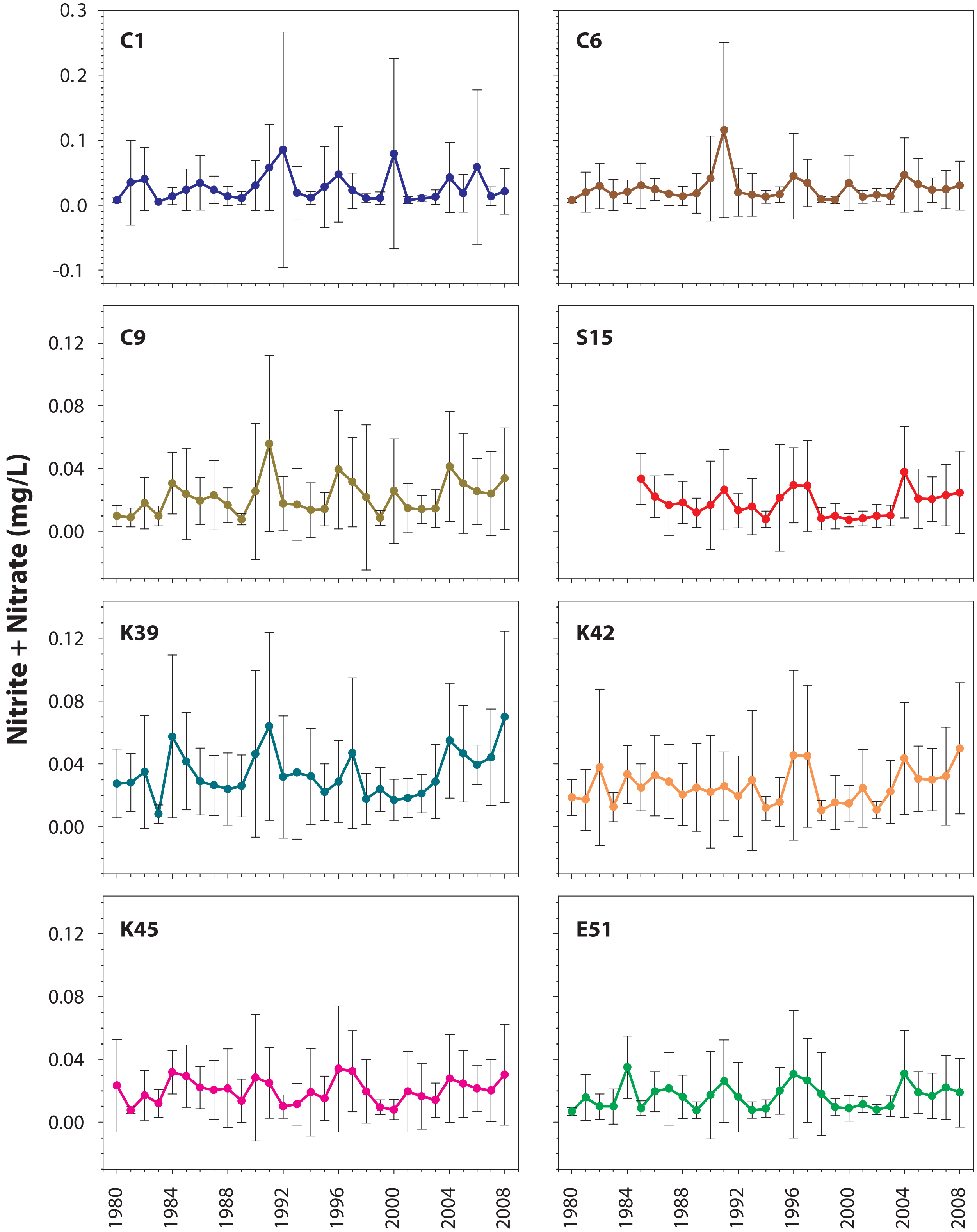
Back to Phosphate section

A4 Total ammonia concentrations at all 8 lake stations. Values for each year are an average (± stdev) of ice-free (May–Oct) concentrations.



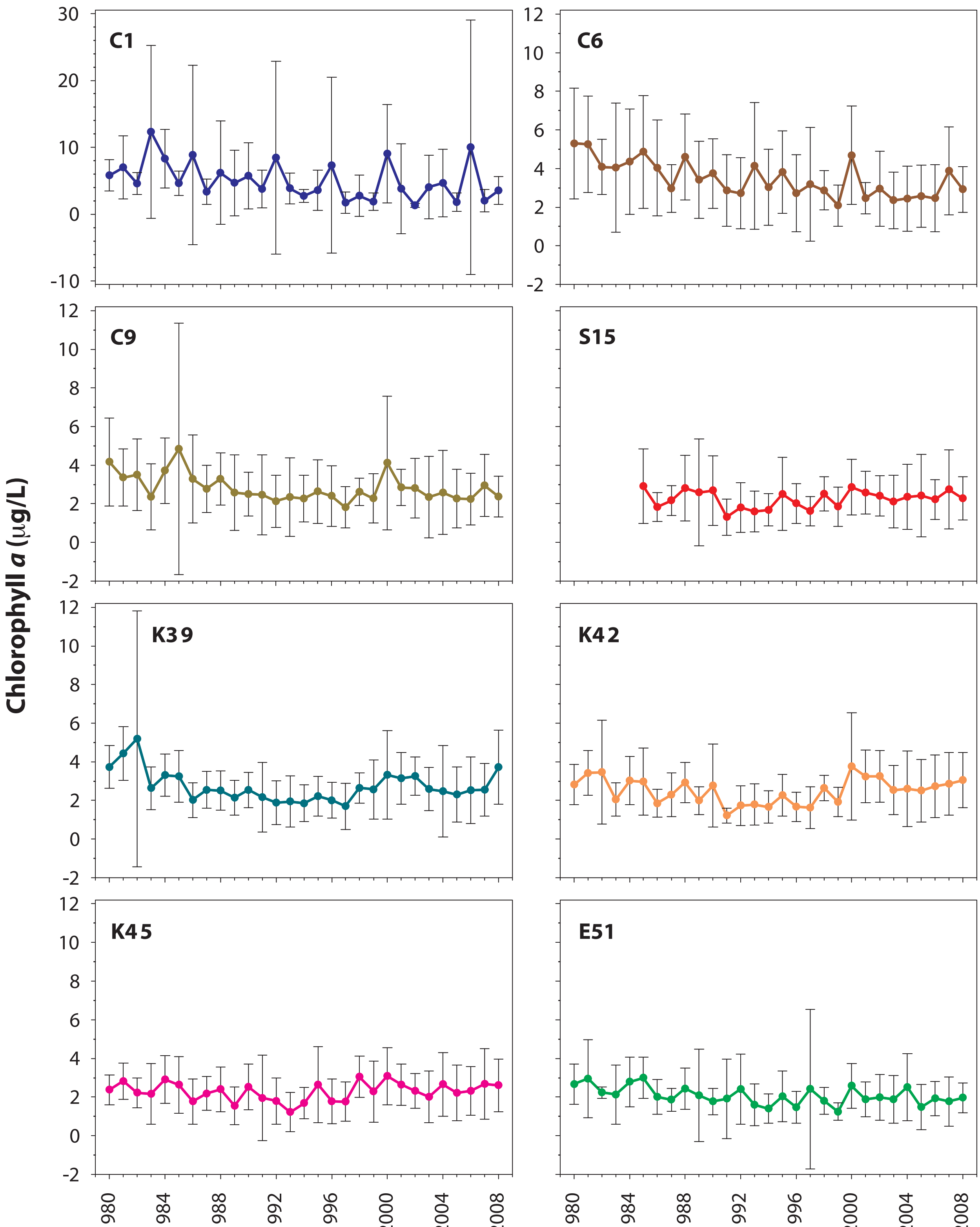
Back to Ammonia section

A5 Nitrate + nitrite concentrations at all 8 lake stations. Values for each year are an average (± stdev) of ice-free (May–Oct) concentrations. Note that the y-axis scale for C1 and C6 are approximately twice as large as the other stations.



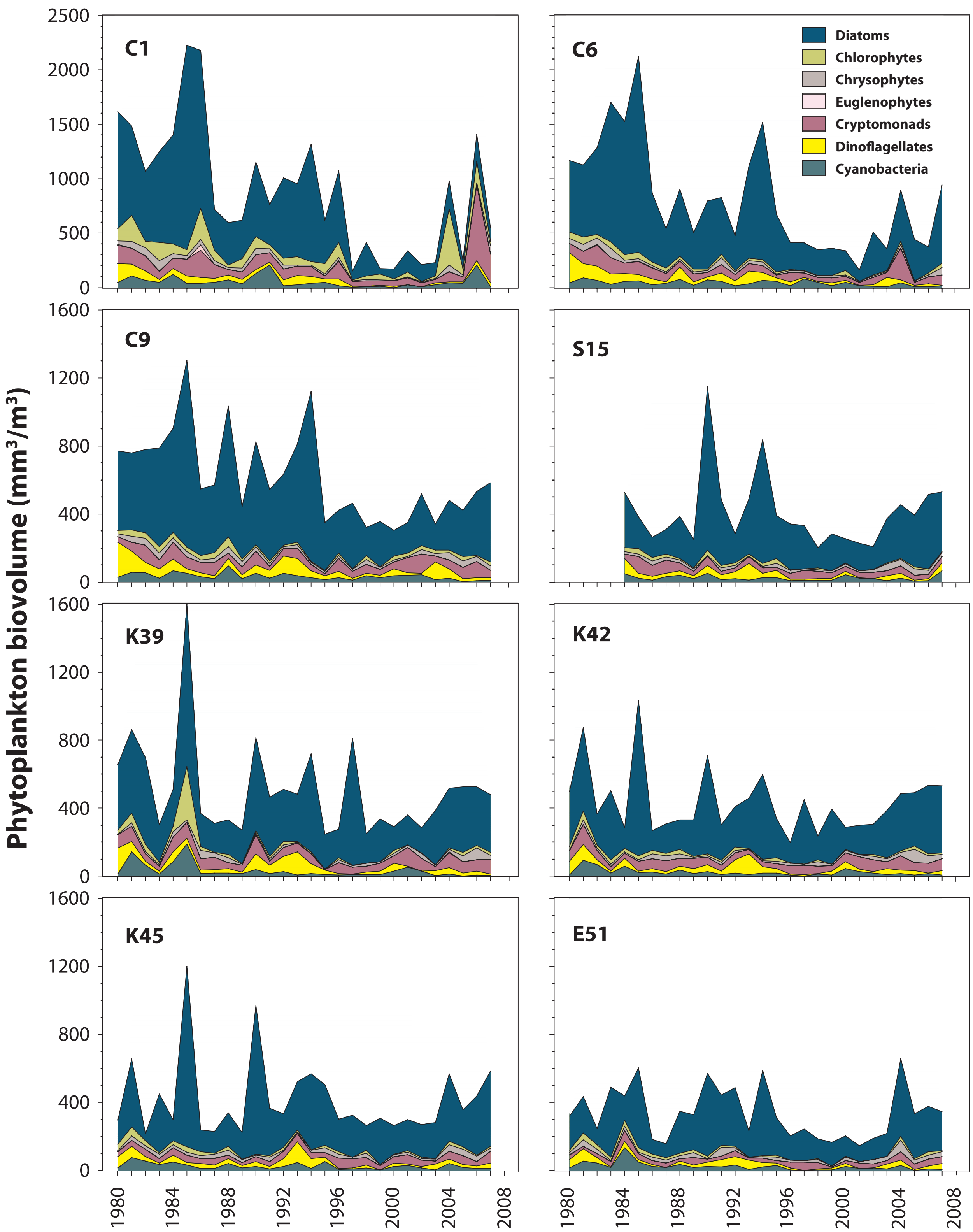
Back to Nitrite+Nitrate section

A6 Chlorophyll *a* concentrations at all 8 lake stations. Values for each year are an average (± stdev) of ice-free (May–Oct) concentrations. Note that the y-axis scale for C1 is approximately twice as large as the other stations.



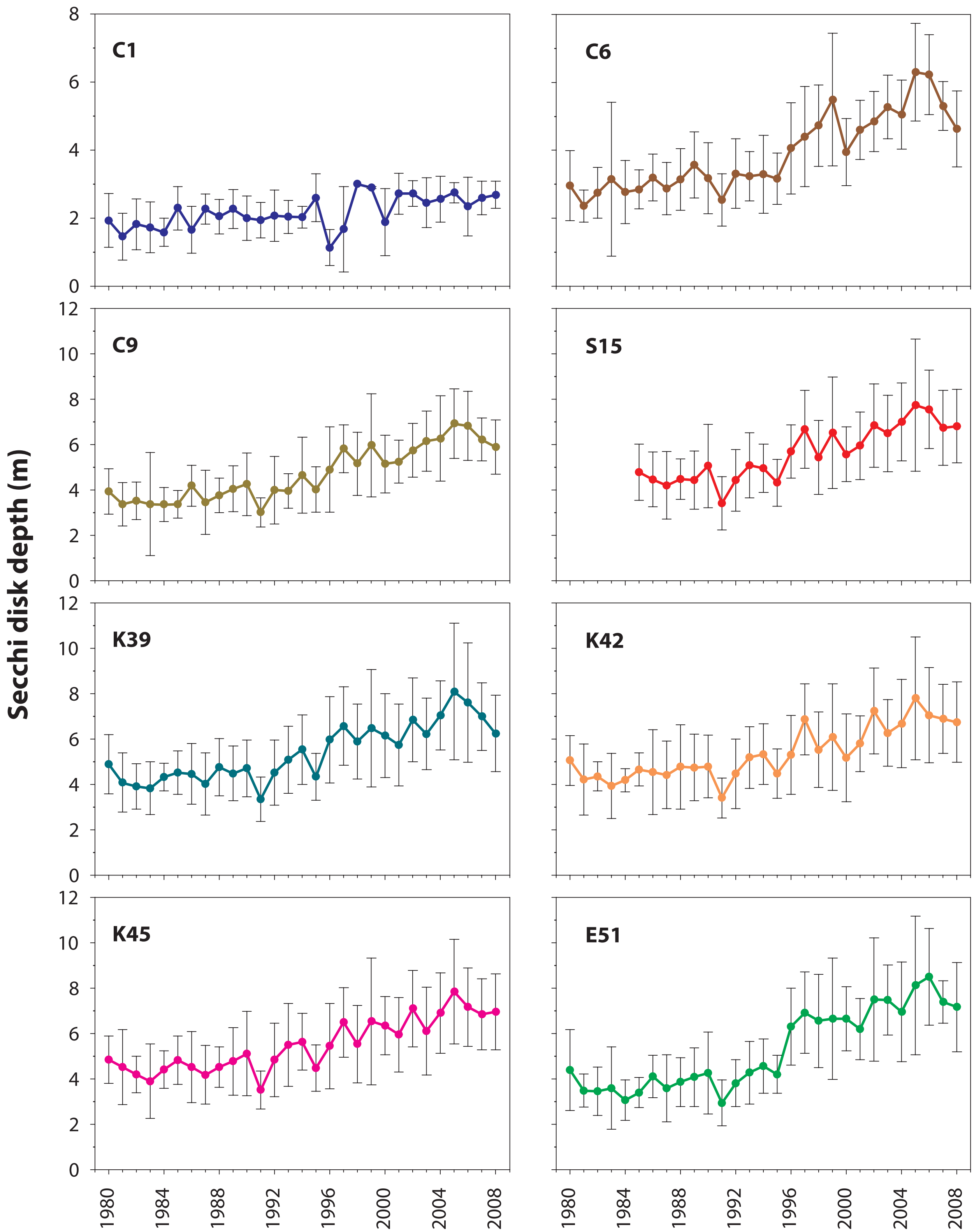
Back to Chlorophyll section

A7 Phytoplankton biovolume proportioned by group at all 8 stations. Values for each year are from a seasonal composite sample. Note that the y-axis scale for C1 and C6 are approximately 1.5 times larger than the other stations.



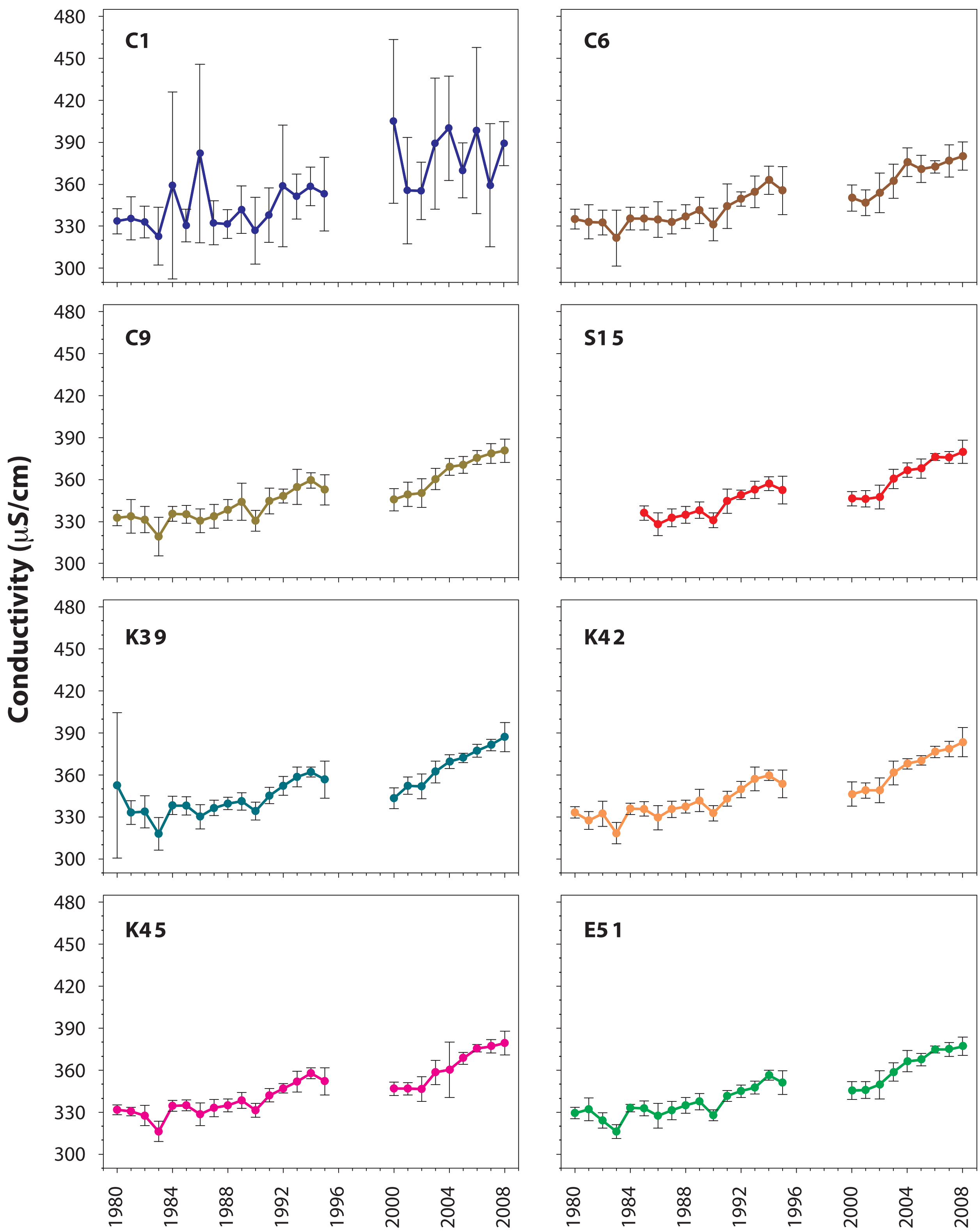
Back to Phytoplankton section

A8 Secchi disk depth at all 8 lake stations. Values for each year are an ice-free (May–Oct) average (± stdev). Note that the y-axis scale for C1 and C6 are smaller than the other stations, and that the maximum depth at C1 is 3 m.



Back to Secchi section

A9 Conductivity at all 8 lake stations. Values for each year are an ice-free (May–Oct) average (± stdev).



Back to Conductivity section

Get Involved

PROTECTING LAKE SIMCOE IS A PARTNERSHIP AMONG ALL OF US.

You can contact:

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Tel: 416-325-4000 or 1-800-565-4923
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For more information contact the Public Information Centre toll free number at 1-800-565-4923, or 416-325-4000 in Toronto

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Water Quality

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